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Contract NOas 56-506-c
Report RMI-103-P3
August 15, 1956

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XLR40-RM-2 TURBOROCKET SUPERPERFORMANCE PROPULSION SYSTEM DEVELOPMENT

THIRD BI-MONTHLY REPORT

Rocket Propulsion ... Aircraft Industry

RMI

REACTION MOTORS, INC.
DENVILLE, NEW JERSEY

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Reaction Motors, Inc.

Report RMI-103-P3

XLR40-RM-2

SUPERPERFORMANCE TURBOROCKET

PROPULSION SYSTEM DEVELOPMENT

CONTRACT NOa(s) 56-506-c
REPORT PERIOD: May 1, 1956 to June 30, 1956 - RMI Project 103

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I. INTRODUCTION

Under contract NOa(s) 56-506-C, this contractor has undertaken the development of an experimental variable thrust turborocket propulsion system for high altitude superperformance of piloted aircraft. The program includes the development of a basic turborocket engine, hydrogen peroxide upstream components, and the integration of the engine and upstream components into an operating propulsion system. The scope of the contract also includes pre-flight rating testing of the propulsion system and the delivery of two powerplants.

The XLR40-RM-2 turborocket engine development program, under contract NOa(s) 56-506-C calls for the following items:

1. The design and development of an experimental, variable thrust, liquid propellant rocket engine for altitude superperformance of a piloted interceptor aircraft.

2. Conducting a program to improve catalyst life with hydrogen peroxide as manufactured by the E.I. duPont de Nemours Chemical Company and the Buffalo Electro Chemical Corporation, and contributing data to be applied to a specification for hydrogen peroxide to be issued by the Bureau of Aeronautics.

3. Conducting preliminary flight rating tests on the engine developed under Item 1 above.

4. Fabricating, acceptance testing and furnishing two engines of the design approved under Item 3.

A summary of the nominal performance characteristics of the predicted powerplant is given below:

Thrust (variable)	3500 to 8000 lbs
Oxidizer	90% H_2O_2
Fuel	JP-5
Specific Impulse	239 sec at 8000 lbs and 50,000 ft. 237 sec at 3500 lbs and 50,000 ft.

2. SUMMARY

2.1 ENGINE DEVELOPMENT

The most significant aspect of the engine development program of this period has been the integrated operation of the turbopump, gas generator, and thrust chamber assemblies (See Figure 1). Integrated testing was made possible through the successful operation of the turbopump "bootstrapping" system (see Section 2.1.3), the satisfactory functioning of the gas generator and "sonic choke" and the use of a flanged Al-Fin thrust chamber. Life testing of a catalyst bed continued from the preceding report period and a total of three hours of satisfactory operation was accrued, at which time testing was arbitrarily stopped. Upon termination of this testing, it was found that the catalyst bed was still in operable condition and was potentially able to render a considerable amount of additional operating time as a catalyst.

Re-evaluation of the XLR40-RM-2 engine design policy based on the successful operation of the integrated engine with the prototype "sonic choke" configuration has indicated that the advantages of perfecting the evaluation type hardware currently far outweigh the merits of undertaking the fabrication and check-out of so called "formal" design hardware. The availability of major component designs capable of timely modification, and the application of the same control and accessory components, will permit the assembly and operation of a throttleable engine at an earlier date. The continued use of evaluation type hardware has the added advantage of the direct applicability of test data obtained to date. The introduction of the formal engine design at this stage of the program would produce a number of functional problems caused by new structural designs and spatial relationships. Evaluation hardware, is slightly heavier than the more refined formal design, but weight reduction can be readily attacked with straight forward design techniques.

Of the two engine designs established in the last report period to provide a method of overspeed control, the "sonic choke" configuration promises to be the most effective. The flow control principle of the "sonic choke" proved to be functionally acceptable during actual hot test runs and in all cases fuel ignition, which was anticipated as a potential problem with this configuration, was as satisfactory and reliable as before. Stable engine operation was obtained in all cases.

2.1.1 Thrust Chamber - Gas Generator

Emphasis has continued on the development of the Al-Fin thrust chamber design. Six (6) Al-Fin chambers were fabricated during this period,

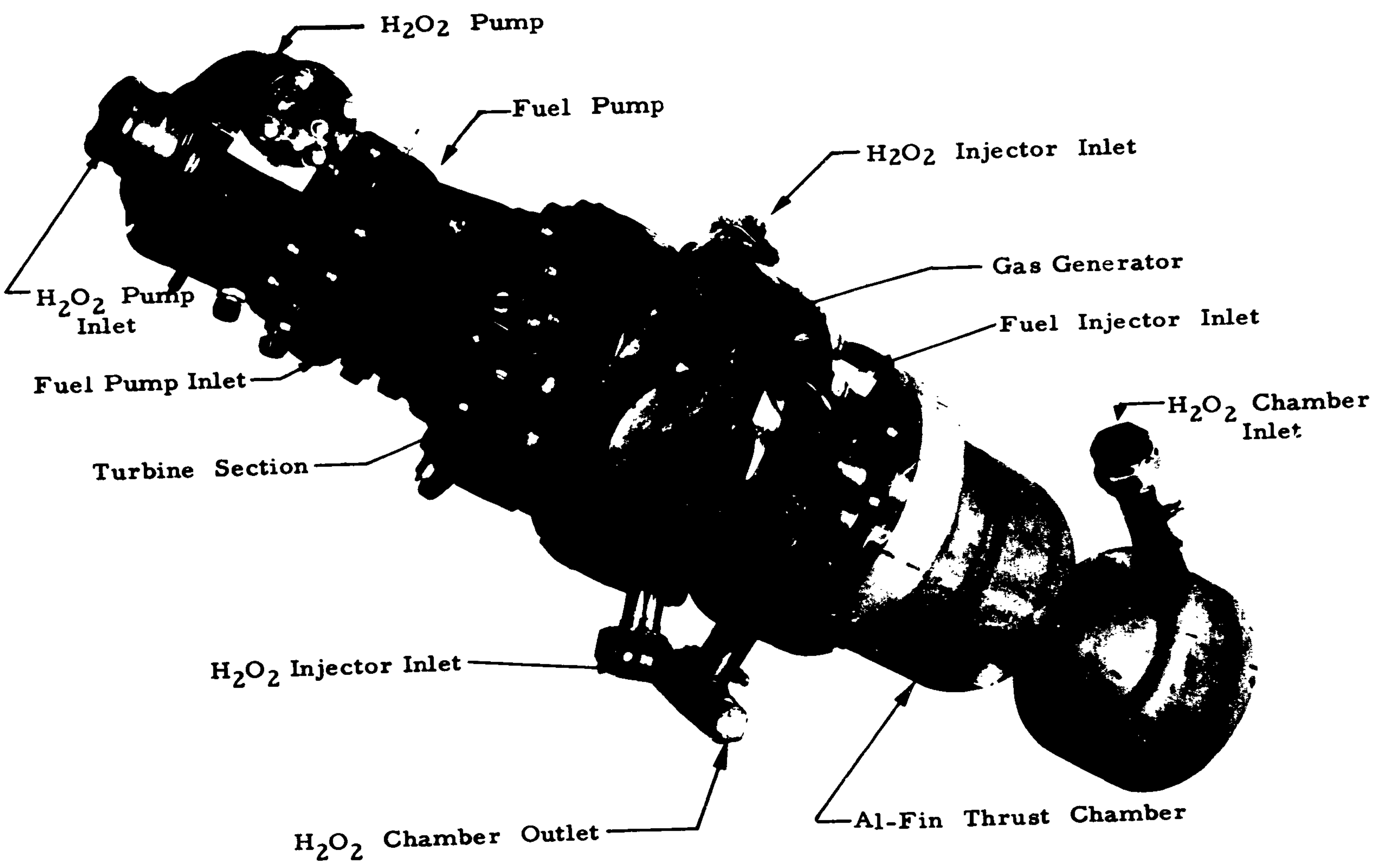

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FIGURE 1
TITLE

PHOTO NO. 103-595
REPORT RMI 103-P3

XLR40-RM-2 TURBOENGINE ASSEMBLY

five of which were evaluated during pressurized engine testing or integrated testing with the turbopump and gas generator. Two of the chambers were tested successfully at high chamber pressure for periods in excess of 2.5 minutes each. These runs were terminated by a failure of the Rokide "Z" coating in a localized area which exposed the base aluminum and caused it to burn. Failure of the Rokide "Z" coating has been attributed in part to the problems which have been encountered in respect to the Al-Fin castings. Porosity and the lack of homogeneity have been the major casting problems. An investigation of casting procedures has resulted in a modification of the chamber casting technique, and improved castings are now being procured.

A catalyst bed operated with Becco hydrogen peroxide performed satisfactorily for over three hours. At the end of this period the decomposition efficiency appeared unchanged and pressure drop through the catalyst bed was less than the 180 PSI allowed by the engine pressure drop budget (See Appendix B of Report RMI 103-P2). Similar life tests with duPont hydrogen peroxide will be run, preferably in conjunction with other evaluations in order to use the peroxide most efficiently.

An improved method of catalyst bed "break-in" has been developed. The new technique requires three brief low pressure hydrogen peroxide injections to the catalyst bed. After each injection, a short period of decomposition occurs.

2.1.2 Fuel Injection

At present, emphasis is being placed on the design and testing of a conical sheet, poppet type fuel injector. Tests have been conducted with the "sonic choke" and ceramic thrust chambers and in certain tests a cylindrical extension was added to the ceramic thrust chamber to determine the effect of increased L*. Satisfactory ignition was achieved with the "sonic choke" on all test firings. Performance curves and the conclusions drawn from this data are described in section 3.2 of this report.

The fuel injector valve which will provide face shut-off of the fuel using a poppet type injector, will be modified for use in the existing evaluation type engine. The internal details of the valve will remain essentially unchanged. The valve has not yet been fabricated and therefore the changes are, at present, limited to the assembly and detail drawings.

2.1.3 Turbopump

Two turbopumps, Serial Numbers one and two, were assembled during this report period and preliminary tests with propellants were conducted.

Thrust loads on the bearings were balanced, the pump discharge orificed to the required flow rates, and the "bootstrap" staring and operating characteristics were checked at speeds of 6,400 RPM to 14,900 RPM and found to be satisfactory.

The term "bootstrapping" describes a significant feature of this engine, namely the inherent abilitv to start the engine without a separate starting system. The "bootstrap" start is accomplished by supplying 90% H_2O_2 to the engine hydrogen peroxide pump inlet at the pressure developed by the boost pump. When the engine propellant valve is opened, the resulting flow through the gas generator and turbine starts the turbopump. The speed of the turbopump increases rapidly as the hydrogen peroxide pump discharge pressure rises, and threrefore, turbine power available for pump acceleration increases. Satisfactory "bootstrap" starting was achieved in all tests.

An integrated thrust chamber, gas generator, and turbopump run was conducted on a bi-propellant basis for ten seconds with results sufficiently encouraging to attempt a longer duration run. This attempt was terminated after 15 seconds of bi-propellant operation, when the steam seal failed, causing considerable damage to the steam seal case and the shaft. It was concluded that the carbon ring seals broke and the resulting increased friction precipitated the burning which damaged these components. Replacement of the carbon rings with alternate labyrinth type seals is now under way.

2.1.4 Valves and Engine Controls

Completion of the system function analyses for the "sonic" and "non-sonic" choke engine systems, as described in Report RMI 103-P2, made it necessary to perform a new malfunction analysis to insure that the systems, as designed, conform to the safety requirements of Specification MIL-E-5149A (ASG). This analysis was undertaken and completed during this period, and changes to the system schematic diagrams are being made.

Engine tests completed during the report period show that the "sonic choke" will effectively limit overspeed of the turbopump. As a result, the decision has been made to concentrate development on this engine system. This decision simplifies the system control problem in may subtle ways. Specifically, it means that the hydrogen peroxide shut-off valve need not incorporate a fast acting overspeed feature and that engine stability is better assured. Analog simulation of the "sonic choke" engine indicated the same overspeed and stability characteristics as the actual engine.

Component functional requirements have been completely defined and designs for all components to be fabricated at RMI have been completed. Fabrication and procurement of engine components is approximately 50% complete and evaluation of vendor components which have been received is in progress. The RMI design hydrogen peroxide throttle valve has been fabricated and bench tested. Its throttling ability and stability have been successfully demonstrated and integration with the turbopump engine will take place in the near future.

2.2 OXIDIZER SUPPLY SYSTEM

The procurement survey based on the preliminary design requirements of the oxidizer supply system was continued. Final design and procurement of components can not be accomplished, however, until Chance Vought Aircraft assigns personnel to work on the system requirements.

2.3 AIRFRAME LIAISON

Contact was maintained with Chance Vought Aircraft during this period. A conference was held at Princeton University on June 6, 1956 with representatives of the Forrestal Research Center, Chance Vought Aircraft and Reaction Motors, Inc. General system design and PFRT requirements were discussed. The most pertinent conclusion reached at this conference was that engine PFRT could be satisfactorily conducted from the standpoint of system stability, without aircraft tankage if Chance Vought Aircraft H_2O_2 Lines and the design boost pump well are used. A conference was also held at Reaction Motors on June 12 between representatives of BuAer and RMI during which the general work status of CVA and RMI was discussed.

2.4 HYDROGEN PEROXIDE CONTAMINANT STUDY

Testing during this period has been conducted with 90% H_2O_2 from tank car lots of both Becco and duPont hydrogen peroxide. Life testing, and testing of hydrogen peroxide at the proposed upper limit of contamination concentrations has been conducted and results are presented in section 3.5 of this report in tabular form. One successful life test on a small ROR-size bed has been completed with Becco H_2O_2 and one with duPont H_2O_2. Contaminant tests have indicated satisfactory operation, but questionable life expectancy.

Work to develop analytical techniques for chemical analysis of contaminants in 90% hydrogen peroxide is continuing.

Special catalyst bed testing has begun. This study, primarily directed at investigating methods of reducing bed pressure drop, has not proceeded far enough to obtain any definitive results.

3.0 PROGRESS

3.1 XLR40-RM-2 TURBOROCKET ENGINE DEVELOPMENT

The gas generator and thrust chamber, the fuel injection system and the turbopump comprise the basic turborocket engine. To complete the turborocket engine, a throttle valve, applicable propellant shutoff valves, other control components and various propellant lines, drains and vents are added.

The thrust chamber is regeneratively cooled by the full hydrogen peroxide flow which enters the thrust chamber coolant passages at the nozzle exhaust end and passes forward to a gas generator which houses the catalyst bed. Here, the hydrogen peroxide is distributed evenly over the cross sectional area of the catalyst bed by a multi-holed plate injector. The catalyst bed is an annular assembly containing silver plated screens which decompose the hydrogen peroxide. The decomposition products provide energy to drive the bi-propellant turbopump which is directly coupled to a single radial impulse turbine immersed in the path of these products. Since there is more than enough hydrogen peroxide decomposition products to drive the turbine, a portion of the flow is by-passed. Passing from this region, the oxygen rich decompostion products enter the thrust chamber where JP-5 fuel is injected and burned to release additional energy for propulsive thrust.

During this report period the "sonic choke" design was adopted as the turbine overspeed protection device. This decision evolved from analog computer analyses and satisfactory operation of this configuration with completely satisfactory fuel ignition. In the "sonic" engine, a single annular nozzle installed in the bore of the gas generator directs the hydrogen peroxide decomposition products from the turbine and bypass to the thrust chamber at approximately 0.83 chamber pressure to turbine discharge pressure ratio. Local sonic velocity is produced in the throat and subsonic velocity in the exit under normal bi-propellant operating conditions.

The effectivity of the "sonic choke" as an overspeed protection device was evaluated during monopropellant "bootstrap" starts with the turbopump and thrust chamber. Simulating a condition which should result in a turbine overspeed,(approximately 28,000 RPM) it was found that turbine speed was limited to approximately 20,000 RPM, a satisfactory margin on the overspeed value. Further evaluation of the "sonic choke" as an overspeed protection device is planned for subsequent testing.

A complete review of the status of all major component designs and an appraisal of the comparative advantages of continuing with the evaluation type engine components as opposed to the formal engine configuration, has

led to a decision to continue development of existing evaluation type components. The advantages inherent in this course of action lie primarily in:

(1) The availability of proven component designs capable of "cleanup" in a short period of time.

(2) The direct applicability of all test results obstained to date.

(3) The possibility of operating a throttleable engine at an earlier date (it is anticipated that this will be possible during the next report period).

The evaluation engine design, as it is currently being used, is illustrated in Figure 2.

3.1.1 THRUST CHAMBER AND GAS GENERATOR

Design and Fabrication

For the purposes of maintaining flexibility in the thrust chamber testing program and allowing developmental modifications to be more readily accomplished, it has been decided to continue the current thrust chamber development effort with the flanged type designs (illustrated in Figure 9). Hydrogen peroxide from the regenerative coolant passages of this type chamber is carried to the gas generator by external transfer lines. The existing gas generators can be used with any of the three basic types of thrust chamber designs, currently under consideration, without modification. The three basic chamber types are:

1. Al-Fin
2. "Spaghetti"
3. Concentric Shell

The Al-Fin and the "spaghetti" types are currently considered the primary designs with the Al-Fin in a more advanced stage of development than the other two types. However, during this period considerably greater emphasis has been placed on the "spaghetti" design. The three thrust chamber types are discussed separately in the following paragraphs.

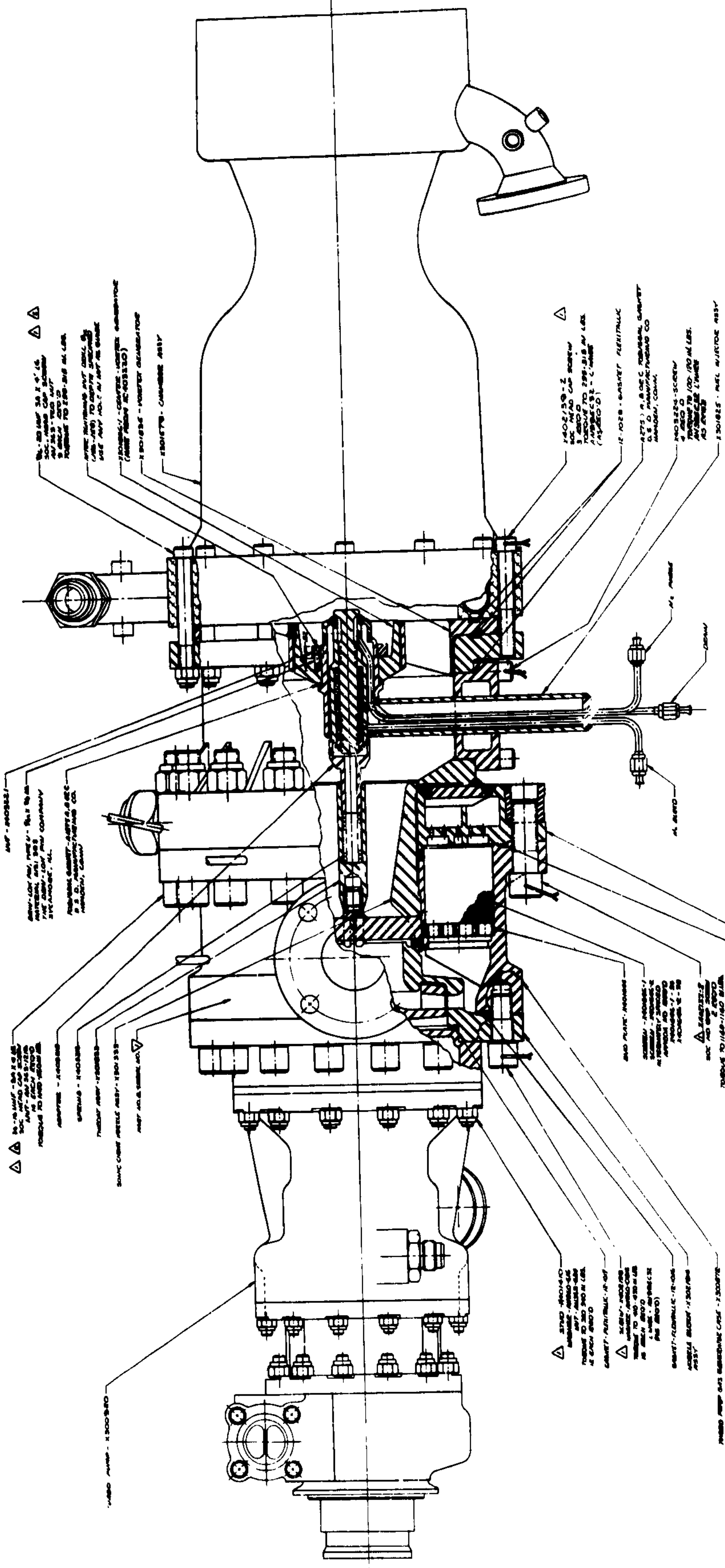

PHOTO NO. 103-638
REPORT RMI 103-P3

FIGURE 2
TITLE

XLR40-RM-2 TURBOENGINE ASSEMBLY

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1. Al-Fin cast aluminum type

The basic structure consists of a multiple stainless steel coolant tube bundle embedded in a matrix of cast aluminum alloy in the shape of a cylindrical combustion chamber with a convergent-divergent nozzle section. A refractory or other lining material is provided to protect the aluminum from hot combustion gases. Rokide Z (zirconia) is currently being used as the refractory coating. The feasibility of the Al-Fin type chamber was initially demonstrated during the first report period (see section 3.1 of Report RMI 103-P1) by a series of bi-propellant tests in which approximately five (5) minutes of operating time was accumulated. The significane of this demonstration lies in the fact that the chamber was the first of its design to be tested and was successfully operated without signs of failure at near rated performance (C*) conditions for an appreciable total duration. Further demonstration of its durability was precluded not by a local failure but by an explosion which resulted from a malfunction of the propellant purge system.

The Al-Fin type chamber has many advantages pertinent to the present program. Some of these advantages are:

(a) It is well suited to high coolant pressure and high differential between this pressure and gas side pressures because of the small diameter coolant tubes used.

(b) It is readily adaptable to design variations such as number and shape of coolant tubes; these changes can be made without altering casting tooling.

(c) It has inherent "hot spot leveling" (ability to readily dissipate heat from local high temperature regions at gas side surfaces) because of the high conductivity of the aluminum surrounding the coolant tubes.

(d) It is relatively independent of velocity distribution in the coolant tubes and therefore is well suited to variable thrust (variable coolant flow rate) operation.

(e) It is relatively easy to manufacture (a simple tube bundle embedded in a cast matrix; tube bundle location in the matrix need not be held to close tolerances).

It is significant that no difficulties have been encountered in the throat region (usually the most troublesome) with the refractory coated chambers. The trouble areas have been prmarily in the exit cone region where casting irregularities have been encountered but now appear to be nearly eliminated.

Although present Al-Fin type chambers are being coated with Rokide Z (zirconia) this is being done primarily to ensure the margin of durability during this development phase. It was indicated during testing of an uncoated chamber that with the exception of the throat region, the coating is not necessary to prevent burning or erosion of the aluminum. Elimination of exposed aluminum in the throat region might have prevented the throat failure which occurred during testing of the uncoated chamber. For the present, work will be continued with refractory coated Al-Fin thrust chambers. When the required thrust chamber endurance has been demonstrated on an integrated turborocket engine, work will be re-initiated on a "non-Rokide" Al-Fin thrust chamber design.

During this report period six (6) Al-Fin thrust chambers were fabricated. Several problems pertaining to the casting of the aluminum around the tube bundle have been encountered. Casting porosity on the internal surfaces of the thrust chamber and a lack of homogeneity (cold shuts) in the cast aluminum were the main problems. As a result of the vendor's experimentation with the casting techniques and procedures, improved castings are now being obtained. During this report period, equipment for Rokide coating operations was installed at RMI. This equipment, operating under a license from The Norton Company, is presently being used to apply refractory coatings to the Al-Fin type thrust chamber. The equipment is capable of internal and external coating operations, not only with the Zirconia presently being used, but Alumina, Silicate and other sprayable refractory coatings.

2. Spaghetti Thrust Chamber

The second thrust chamber type under consideration is of the "spaghetti" type which like the Al-Fin chamber is comprised of a multiple stainless steel tube bundle. In contrast to the Al-Fin thrust chamber configuration with the coolant tubes separated from each other throughout their length, the "spaghetti" design tubes are tangent to one another throughout the entire length of the thrust chamber. Two versions of this "spaghetti" type chamber have been designed and detail drawings completed. The first version of the "spaghetti" chamber contains 45 tubes whose cross sectional areas are round in the throat region and flattened to an ellipitcal shape in the chamber and nozzle exit cone regions. In the second, a 29 tube version, each tube is flattened to an ellipitcal cross sectional shape throughout its entire length. The outer jacket or pressure restraining material can be wire wrapping or aluminum cast around the pre-assembled tube bundle.

The individual coolant passage tubes for the initial "spaghetti" thrust chambers were released for fabrication, and the swaging of standard tubing, which is the first step of the forming operation, is in process. Drawings

for the tooling required to accomplish other tube forming and thrust chamber assembly operations have been completed and fabrication has been initiated.

3. Concentric Shell Thrust Chamber

The third thrust chamber type under consideration for the XLR40-RM-2 turborocket engine is a concentric shell design. Beacuse of the unusually high pressure differential between the regenerative cooling passages and the combustion chamber, a conventional unsupported liner type thrust chamber does not appear feasible. The high pressure differential stems from the fact that in addition to the cooling jacket and injector pressure drops encountered in conventional engine designs, further pressure drops occur in the catalyst bed itself, the turbine and bypass, and the "sonic choke". The first concentric shell thrust chamber design is composed of a stainless steel liner with integrally machined, helical coolant passages to support the liner against coolant pressure collapsing forces. A single liner was released for fabrication during this report period. Other versions of the concentric shell type chamber are being studied.

One of the most recent developments of this period has been the design and fabrication of a Vortex generator to impart a swirling motion to the hydrogen peroxide decomposition products as they enter the combustion zone. This swirl pattern should increase characteristic velocity by virtue of the increased gas turbulence and the effective increase in chamber length (L*) due to the spiral path length. An indication of the possible result of the effective L* increases can be deduced from the increased L* tests described in section 3.2.5 of this report. Of equal importance is the fact that the swirling gas motion also provides a cooler atmosphere adjacent to the chamber wall. This device, shown in figure 3, lies in a plane immediately upstream of the fuel injector. Test evaluation of this device will be conducted with a ceramic thrust chamber during the next report period.

Development of a catalyst bed with acceptable service life characteristics has progressed to date with considerable success. The two conditions which are considered to be a basis for the termination of acceptable performance are:

(1) The failure of the catalyst to yield proper decomposition of the hydrogen peroxide, and

(2) An increase in catalyst bed pressure drop in excess of the 180 PSI allowed by the engine pressure budget.

Thus far, excessive pressure drop appears to be the major problem.

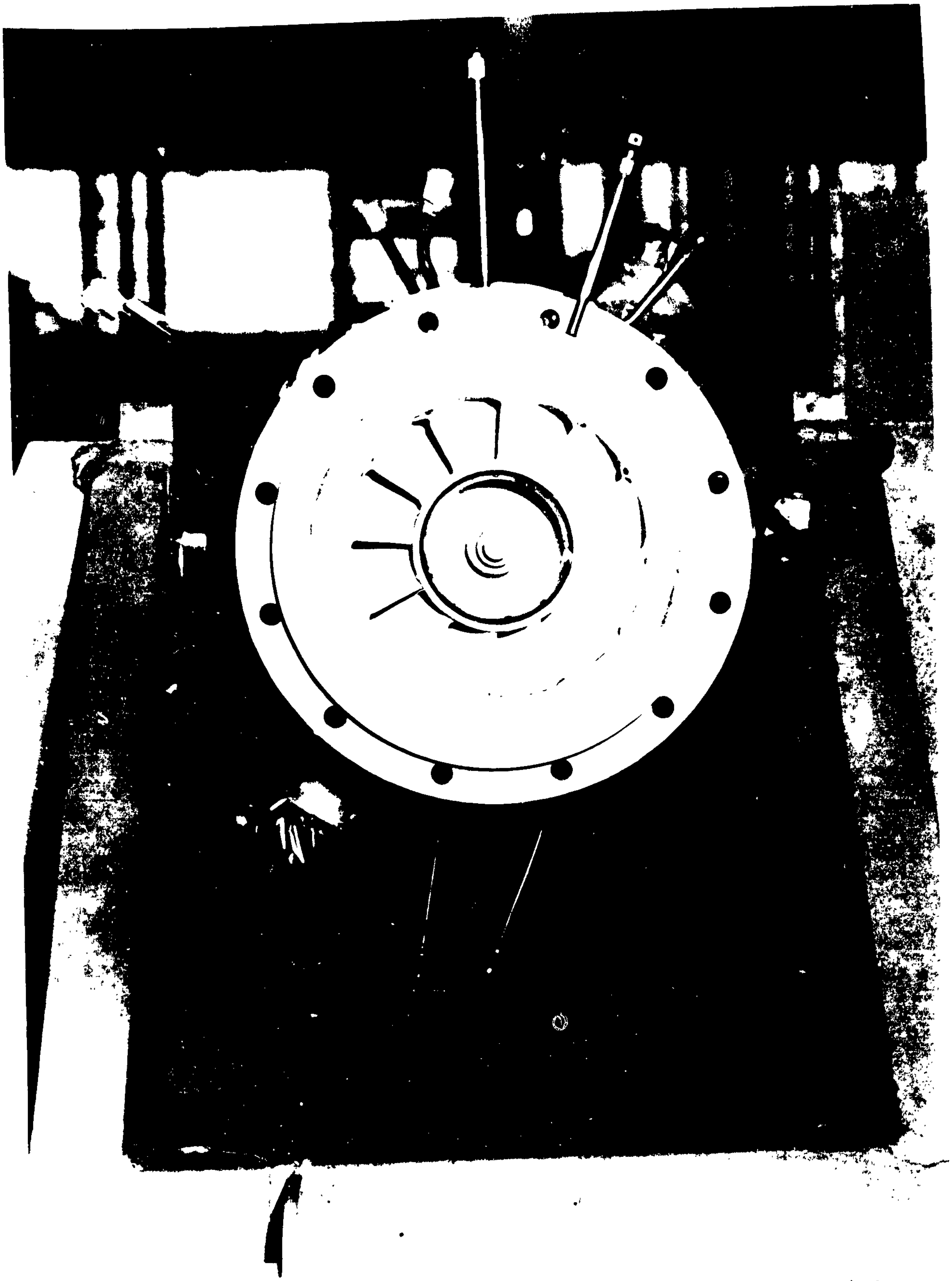

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FIGURE 3
TITLE

PHOTO NO. 103-613
REPORT RMI 103-P3

DOWNSTREAM VIEW OF VORTEX GENERATOR

Despite this, however, more than three hours of satisfactory operation with Becco hydrogen peroxide was completed during this report period. Similar life tests with duPont hydrogen peroxide are in progress. The results of these tests are discussed in detail in section 3.2.3

The attempted use of a shortened catalyst bed was discussed in section 3.1.1 of report RMI-103-P2. It was noted that the apparent lack of success in obtaining satisfactory decomposition after several minutes of operation was not conclusive due to the method then being used for breaking in the bed. It was found in subsequent tests that as much as 10 to 11 minutes of full flow rate operation was required to break-in the catalyst bed. A new method is currently being used which requires much less break-in time. The basic difference between the two methods is in the initial flow rates used. The newly discovered technique involves three, brief, low pressure injections of hydrogen peroxide into the bed; allowing a short interval after each injection for the hydrogen peroxide to "cook" in the bed. Decomposition efficiency is then checked under sustained high flow rates. Thus far it has been found unnecessary to repeat the low pressure injections. A further reduction in bed break-in time appears feasible either by further modifying the low pressure injection technique, or by other catalyst screen activiation processes.

In view of the above, a re-evaluation of the shortened catalyst bed is warranted. Advantages of the shortened bed are:

(a) Reduced pressure drop.

(b) Reduced weight in both the bed and the gas generator which contains the bed.

(c) Reduced engine length.

2.1.2 Fuel Injection

"Sonic choke" fuel ignition and performance evaluation testing was conducted with ceramic thrust chambers and a conical sheet, poppet type, fuel injector. Satisfactory ignition was achieved with the "sonic choke" on all test firings. At an O/F Ratio of 7.0 with the "sonic choke", the conical sheet injector produced characteristic velocity values of:

4350 ft/sec @ P_{ch} = 270 PSIA

4550 ft/sec @ P_{ch} = 550 PSIA

Evaluation of the same injector without the "sonic choke" at an O/F ratio of 7.0 produced characteristic velocity values as follows:

4150 ft/sec @ P_{ch} = 290 PSIA

4350 ft/sec @ P_{ch} = 625 PSIA

It can be noted that C* was improved approximately 4 1/2 to 5% with the "sonic choke".

3.1.3 Turbopump

Assembly, preliminary testing, and bi-propellant testing of the turbopump with the design gas generator and Al-Fin thrust chamber was achieved during this report period. The initiation of preliminary testing of the serial No. 1 turbopump had been delayed when cracks in the pump housing and impeller castings were revealed by X-rays after heat treat (see section 3.1.3 of Report RMI 103-P2). Machined impellers and weld-repaired castings were used to expedite testing and an investigation into the casting problem was initiated.

During this report period the fuel and oxidizer housings were redesigned to eliminate the cracking tendencies. Cracks in the fuel case casting were of the "hot tear" type and occurred in the inlet guide vane section. The inlet vanes are intended to control the flow paths and are not required to contribute to the strength of the parts. Therefore, a gap designed into the casting at the point where the cracks occurred has solved this problem and sound castings are being obtained. Cracks in the oxidizer housings and impellers appear to be due to oxide fold-over during the casting process. This problem was solved through a combination of sectional redesign of the casting and the provision of extra "float-off" ports in the casting mold to provide better flushing of the mold cavity with hot metal. These measures appear to have solved this problem, but as of the end of this report period, an insufficient number of castings have been received to assure complete success.

An investigation of the cracked impeller castings is continuing and fully machined impellers are being used until the casting problem with these particular parts has been resolved.

3.1.4 Valves and Engine Controls

Development progress on engine valves and controls is discussed in the following paragraphs in three basic categories:

1. System analysis and design.

2. Component design and procurement.

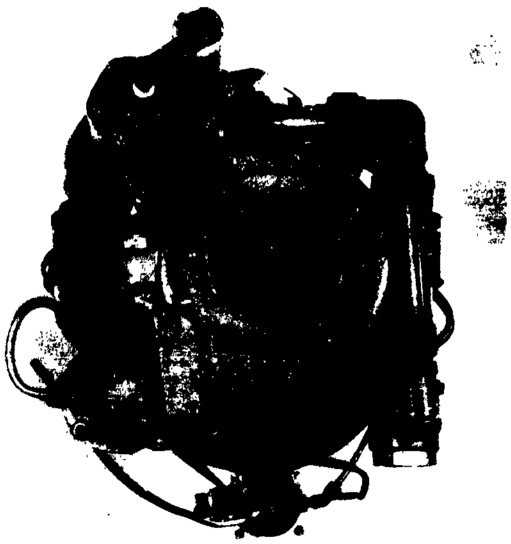
3. Component bench-testing.

Analysis of the engine system from a functional viewpoint is summarized in the piping and electrical schematics presented in section 3.1.4 of report RMI 103-P2. With the finalization of these schematics, a new malfunction analysis was performed and the resulting minor changes to the schematics are being made. The original functional analysis from which these schematics are derived, and the malfunction analysis leading to their revision were both influenced by data obtained from analog simulation and actual engine testing. This data indicates that the sonic choke engine system is stable and that overspeed is successfully limited by the sonic choke.

Emphasis during this report period has been placed on the procurement and testing of engine valves and controls. Designs for all components to be fabricated at RMI have been completed. The engine control system schematics are presently being converted into engine piping assembly and wiring drawings. A wooden mockup incorporating the basic turborocket engine, engine mounted control components, and essential tubing and fittings, has been fabricated to facilitate engine assembly. Figures 4A and 4B show the mockup in two views. This mockup was assembled on the basis of the previously conceived formal engine design. The formal design is similar to the evaluation engine arrangement shown in figure 2 of this report except that integral gas generator and fuel injector assemblies, illustrated respectively in figures 3 and 11 of report RMI 103-P2, were planned. The mockup illustrated in figures 4A and 4B is representative of the evaluation engine configurations except in these two areas, where external thrust chamber to gas generator H_2O_2 transfer lines and connections to a post mounted fuel injector will be required.

Approximately fifty per-cent of the engine control components have been fabricated or procured from selected vendors. Figures 5, 6, and 7 show some of these components. Some difficulty has been encountered in procuring a thermal switch with adequate time response. A transistorized amplifier controller - thermocouple combination is being investigated as a possible alternate to conventional thermal switches.

As a result of the demonstrated ability of the sonic choke to control overspeed, the proportional feed-back (non-integrating) type throttle valve will be incorporated in the engine in the near future. This valve is essentially a pressure regulating valve which is sensitive to inlet (turbopump discharge) pressure. Throttle setting is accomplished by establishing a reference pressure with nitrogen gas on the main piston of the valve.

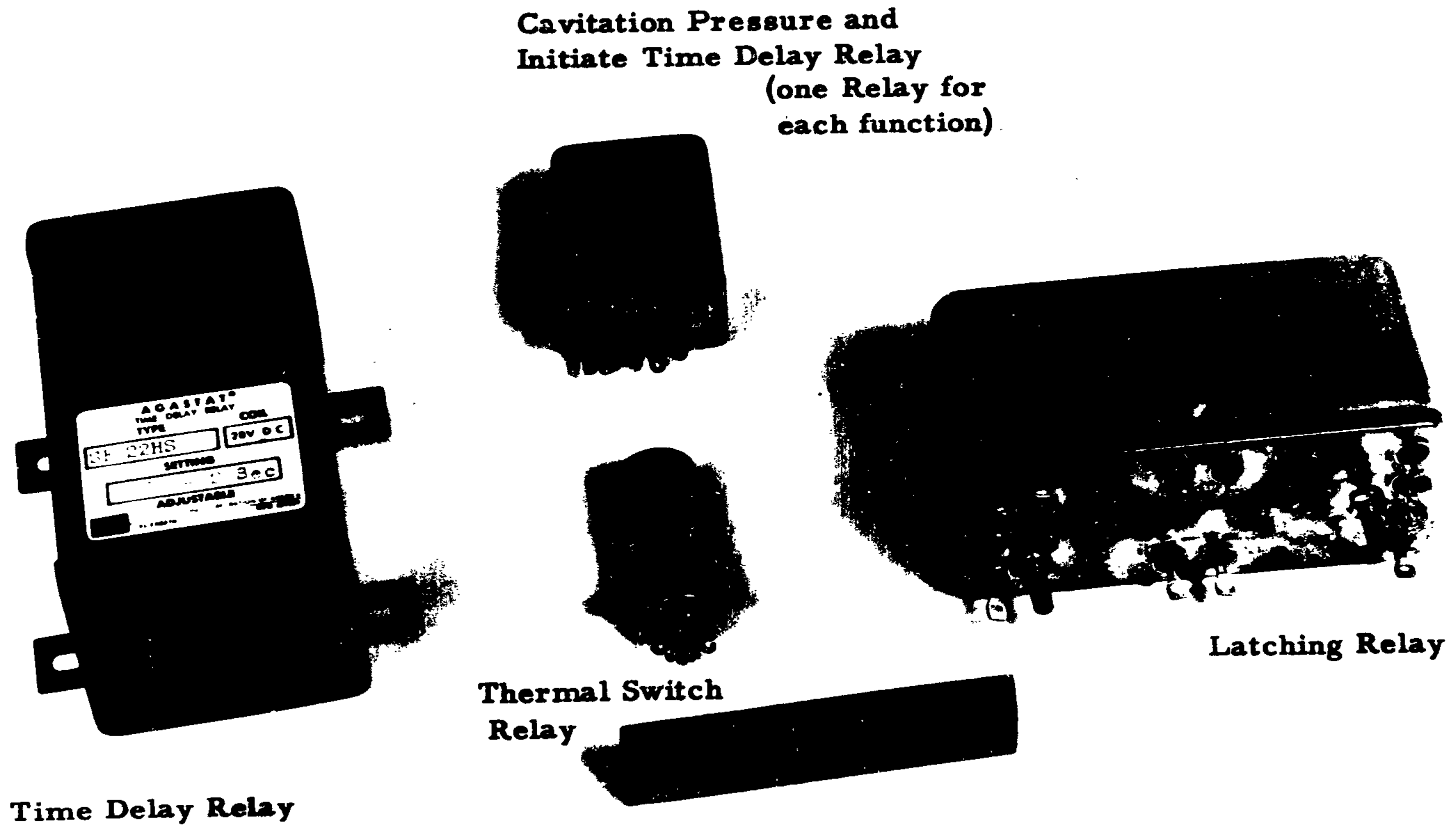


REACTION MOTORS, INC. FIGURE 4 a PHOTO NO. 103-606
CONFIDENTIAL TITLE REPORT RMI 103-P3

XLR40-RM-2 TURBOENGINE MOCKUP (Front View)

REACTION MOTORS, INC. FIGURE 4 b PHOTO NO. 103-608
CONFIDENTIAL TITLE REPORT RMI 103-P3

XLR40-RM-2 TURBOENGINE MOCKUP (Underside View)

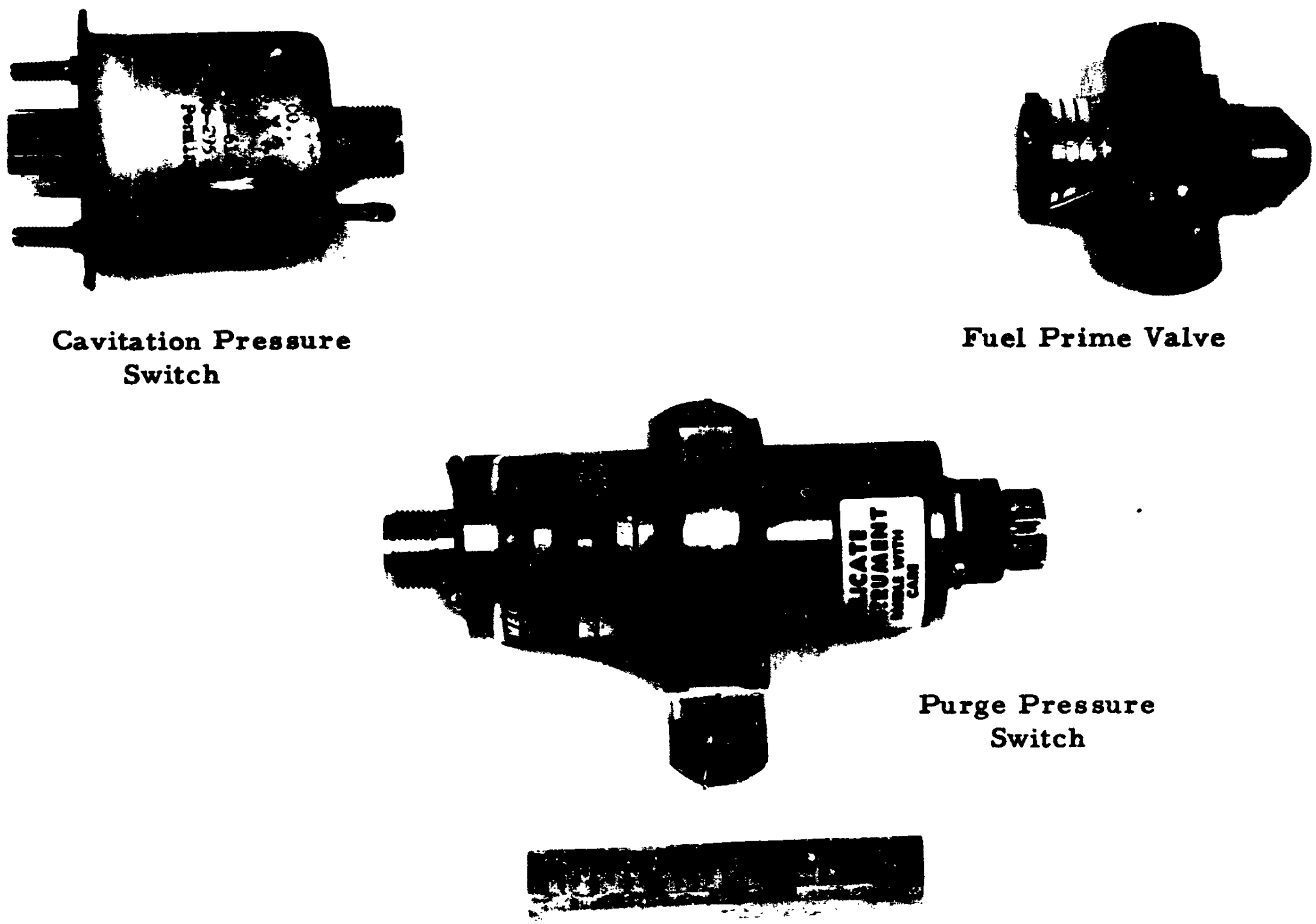


REACTION MOTORS, INC.

FIGURE 5
TITLE

PHOTO NO. 103-617
REPORT RMI 103 P3

XLR40-RM-2 ENGINE CONTROL RELAYS



REACTION MOTORS, INC. FIGURE 6 PHOTO NO. 103-618
TITLE REPORT RMI 103-P3

XLR40-RM-2 CONTROL COMPONENTS

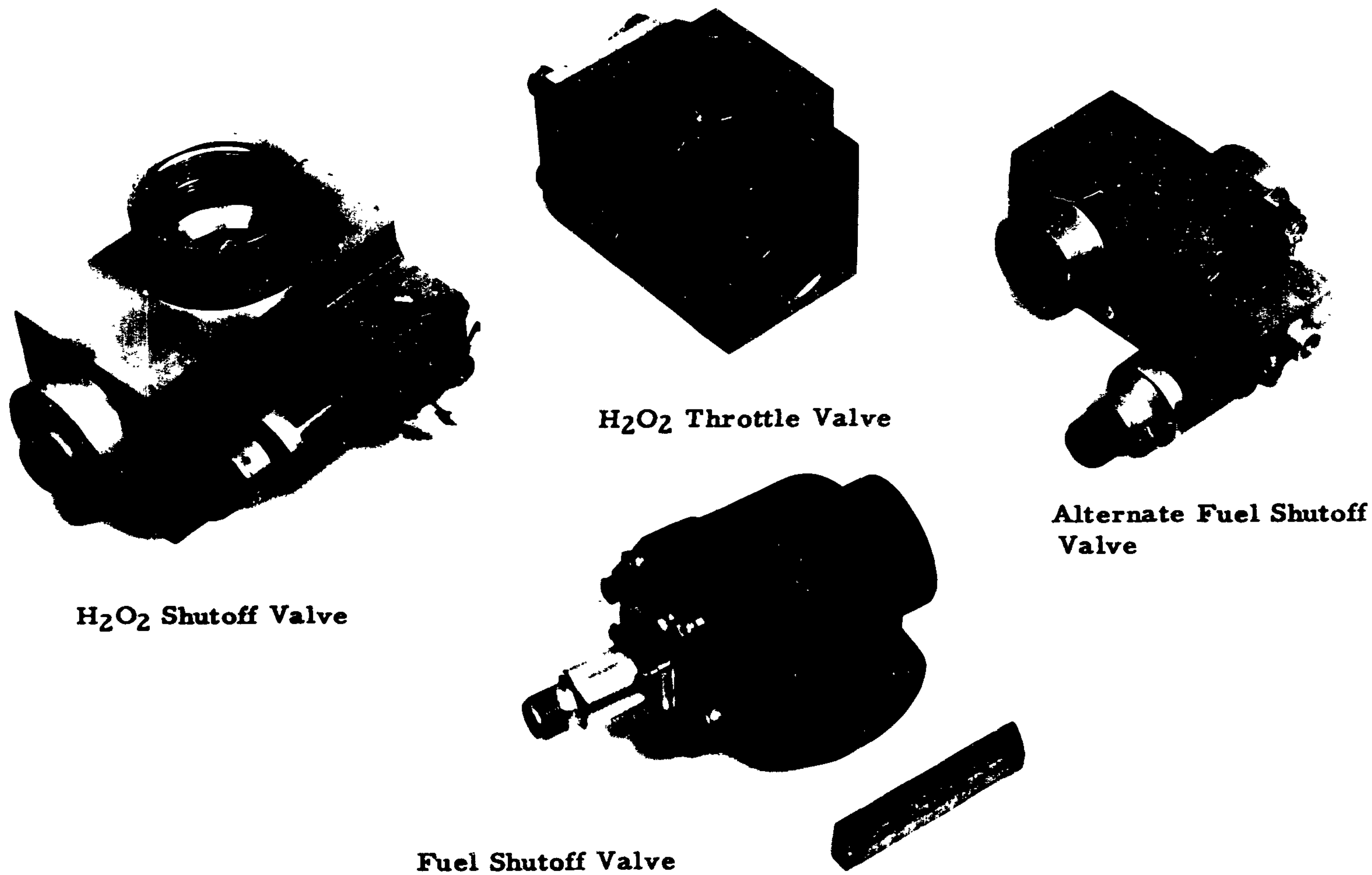


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FIGURE 7 PHOTO NO. 103-616

TITLE REPORT RMI 103-P3

XLR40-RM-2 PROPELLANT VALVES

Bench testing of engine control components is in progress and their integration with the basic turborocket engine is scheduled for the latter part of the next report period.

3.2 TEST OPERATIONS (See Table I)

Engine test operations and component evaluation tests were conducted during this report period in six major categories:

1. Turbopump operation checks including monopropellant and bi-propellant "bootstrap" starting tests.
2. Integrated turbopump, gas generator, and thrust chamber testing.
3. Service life testing of the catalyst bed and gas generator.
4. Pressurized durability testing of the 8000 lb. Al-Fin thrust chamber.
5. Performance evaluation of a basic conical sheet poppet type fuel injector with and without chamber extension sections.
6. Sonic choke ignition and performance evaluation testing.

3.2.1 Turbopump Testing

All turbopump testing during this report period was conducted with the specified propellants and the turbopump "bootstrapping" to operating speed. Two turbopump assemblies were assembled and run. Serial numbers one and two turbopumps are identical with the exception of inducers which are included in the serial number two pump only. Although both pumps were run, the effect of the inducers has not as yet been evaluated.

The objectives of these preliminary tests were:

1. To determine and balance out the thrust load on the bearings.
2. To evaluate turbine and pump starting and operating characteristics, seal and bearing performance, and mechanical reliability of the turbopump.
3. To orifice the pump discharge to the required flow rates.

TABLE 1

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

Date		(5/24/56)					(6/'/56)						(6/4/56)
Run No. (2CX-)		1607	1608	1609	1610	1611	1623	1624	1626	1627A	1627B	1628	1629
P_{ch}	(psia)	629	616	616	616	609	295	285	285	389	601	416	595
W_o	(lb/sec)	30.1	28.49	29.01	28.22	28.77	13.52	13.5	14.1	20.3	30.35	20.35	27.4
W_f	(lb/sec)	1.77	2.93	3.04	2.69	3.14	2.76	3.88	2.35	2.29	3.88	3.97	2.32
W_t	(lb/sec)	31.9	31.42	32.05	30.91	31.91	16.28	17.38	16.45	22.59	34.23	24.32	29.7
O/F		17.0	9.72	9.54	10.49	9.162	4.899	3.48	6.0	8.865	7.822	5.126	11.82
C*	(ft/sec)	4667	4642	4551	4719	4519	4547	4104	4370	4343	4428	4281	4720
F	(lb)	6870	6630	6600	6600	6670	3000	2930	2910	3830	6930	4660	6300
I_{sI}	(lb/lb-sec)	215	211	206	214	209	184.3	168.6	176.9	169.5	202.5	191.6	213.0
C_F		1.484	1.46	1.46	1.46	1.49	1.304	1.321	1.302	1.256	1.471	1.44	1.445
t	(secs)	1.89	1.92	1.78	1.62	1.75	1.52	17.75	3.73	5.66	3.[illegible]6	4.26	1.04
$\Delta P_{C\ B}$	(psi)	198	179	187	164	181	---	92	123	125	135	145	---
ΔP_f	(psi)	275	318	318	193	187	227	229	79	---	---	263	264
$\Delta P_{T\ C}$	(psi)	103	205	115	115	117	---	---	---	---	---	---	95
$\Delta t_{T\ C}$	(°F)	14	19	23	20	38	---	---	---	---	---	---	24
Thrust Chamber		301298A Ser. No. 7 → Al-Fin Rokide Z Coating					300868 Ser. No. 410-4 → Ceramic						301298 Ser. No. 8 Al-Fin
H_2O_2 Injector		301325 Ser. No. 523-1 →											301325 Ser. No. 217-1
Fuel Injector		301629 Ser. No. 53 1 → Radial Stream					300922 Ser. No. 519-3 → Poppet (0.060 Gap)						
Catalyst Bed Serial No.		401646 Ser. No. 8 →					401646 Ser. No. 12 →						401646 Ser. No. 8
Sonic Choke		Sonic Choke Not Used →					301333 Ser. No. 510-1 →						
Sonic Choke Throat Area (in.²)							1.54 in.² →						
Sonic Choke Pressure Ratio							---	0.890	0.870	0.796	0.845	0.848	

Remarks:

Run Nos. 1607-1611: Durability testing of Al-Fin type thrust chamber. Coating flaking experienced in throat and chamber sections. Chamber aluminum matrix failed locally at throat on 2CX1611 in region of flaked coating. One tube burned through.

Run Nos. 1623-1628: Initial performance evaluation test firings with the sonic choke installed. Downstream edge of choke burned on 2CX1627B. Further edge burning on 2CX1628.

Run No. 1629: Durability testing of Al-Fin type thrust chamber. Coating flaking experienced. Chamber removed for re-coating.

TABLE 1 (CONT)

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

		1630A	1630B	1630C	1630D	1631A	1631B	1632A	1632B	1633A	1633B	1634A	1634B	1634C	1634D	1634E
Date		(6/5/56)														
Run No. (2CX-)		1630A	1630B	1630C	1630D	1631A	1631B	1632A	1632B	1633A	1633B	1634A	1634B	1634C	1634D	1634E
P_{ch}	(psia)	604	612	640	634	288	294	285	289	279	298	290	644	294	296	297
W_o	(lb/sec)	31.4	32.3	32.3	32.4	14.0	14.2	14.6	14.6	14.85	14.8	14.85	31.0	14.95	14.65	14.65
W_f	(lb/sec)	4.07	4.03	4.67	5.24	3.53	3.46	2.74	2.41	2.38	2.32	2.32	5.45	2.3	2.73	2.74
W_t	(lb/sec)	35.47	36.33	36.97	37.64	17.53	17.66	17.34	17.01	17.23	18.12	19.17	36.45	17.25	17.38	17.39
O/F		7.715	8.015	6.916	6.183	3.96	4.11	5.33	6.06	6.24	6.39	6.4	5.7	6.49	5.37	5.35
C*	(ft/sec)	4295	4250	4370	4250	4150	4210	4150	4280	4080	4165	4265	4580	4310	4310	4325
F	(lb)	6800	7080	7360	7400	3000	3050	2960	3000	2900	2900	2980	7450	3000	3080	3070
I_{sp}	(lb/lb-sec)	192	195	199	196	171.5	173.2	165.5	176.3	170.5	170.5	174.2	204.1	174.5	178	177.5
C_F		1.436	1.51	1.46	1.485	1.33	1.324	1.325	1.325	1.370	1.309	1.31	1.475	1.30	1.33	1.32
t	(secs)	5	5	5	7.8	6	5	5	5.9	5	6.3	4	4	4	4	4
$\Delta P_{C\ B}$	(psi)	225	212	192	184	159	146	148	146	149	147	106	183	151	151	146
ΔP_f	(psi)	238	230	402	412	184	178	115	111	92	89	78	240	70	117	116
ΔP_{TC}	(psi)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
$\Delta t_{T\ C}$	(°F)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Thrust Chamber		300868 Ser. No. 410-3 Ceramic →														
H_2O_2 Injector		301325 Ser. No. 217-1 →														
Fuel Injector		300922 Ser. No. 519-3 Poppet (0.060 Gap) →										301629 Ser. No. 53-1 Radial Stream →				
Catalyst Bed Serial No.		401646 Ser. No. 8 →														
Sonic Choke		Sonic Choke Not Used →														
Sonic Choke Throat Area (in.^{2})																
Sonic Choke Pressure Ratio																

Remarks: Run Nos. 1630-33. Performance evaluation of conical sheet poppet-type fuel injector.
Run Nos. 1634A-E: Performance evaluation of radial stream-type fuel injector.

TABLE 1 (CONT)

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

Date		(6/5/56)			(6/6/56)				(6/7/56)			(6/8/56)
Run No. (2CX-)		1634F	1634G	1634H	1636	1637	1638	1639	1640A	1640B	1640C	1641
P_{ch}	(psia)	604	623	643	564	571	579	574	639	649	675	578
W_o	(lb/sec)	31.0	31.7	30.8	26.2	27.1	27.3	26.75	31.8	32.3	31.0	26.7
W_f	(lb/sec)	4.45	4.43	5.46	4.2	4.02	4.22	4.25	3.55	3.49	4.9	4.37
W_t	(lb/sec)	35.45	36.13	36.26	30.4	31.12	31.52	31.00	35.35	35.8	35.9	31.07
O/F		6.97	7.16	5.64	6.25	6.75	6.47	6.30	8.958	9.2	6.3	6.1
C*	(ft/sec)	4420	4350	4475	4400	4370	4320	4360	4523	4537	4705	4380
F	(lb)	6950	7110	7420	6030	6100	6200	6150	7390	7530	7820	6230
I_{sp}	(lb/lb-sec)	196.5	197	205	198.5	196.0	193.5	198.5	209	210	218	200
C_F		1.47	1.46	1.47	1.44	1.45	1.415	1.44	1.487	1.492	1.49	1.47
t	(secs)	5	5	6	5.66	20.3	62.6	54.3	3	2	2	20.2
$\Delta P_{C\,B}$	(psi)	200	204	184	156	167	139	159	183	165	168	169
ΔP_f	(psi)	259	240	241	---	---	---	---	234	230	369	274
$\Delta P_{T\,C}$	(psi)	---	---	---	96	102	102	96	---	---	---	92
$\Delta t_{T\,C}$	(^oF)	---	---	---	---	---	---	---	---	---	---	19.5
Thrust Chamber		300868 Ser. No. 410-3 → Ceramic			301298 Ser. No. 8 → Al-Fin - Rokide Z Coating				300868 Ser. No. 410-2 → Ceramic (carbon steel extension)			301298 Ser. No. 8 Al-Fin - Rokide Z Coating
H_2O_2 Injector		301325 Ser. No. 217-1 →			301325 Ser. No. 52-1 →							301325 Ser. No. 523-1
Fuel Injector		301629 Ser. No. 53-1 → Radial Stream			300922 Ser. No. 519-3 → Poppet (0.060 Gap)							300922 Ser. No. 519-2 Poppet (0.060 Gap)
Catalyst Bed Serial No.		401646 Ser. No. 8 →			B-1 →							Serial No. B-1
Sonic Choke		Sonic Choke Not Used →										
Sonic Choke Throat Area (in.^{2})												
Sonic Choke Pressure Ratio												

Remarks:
- Run Nos. 1634F-H: Performance evaluation of radial stream-type fuel injector.
- Run Nos. 1636-1639: Durability testing of Al-Fin type thrust chamber. Nozzle erosion in region of coolant inlet manifold.
- Run Nos. 1640A-C: Performance evaluation of conical sheet poppet type injector with increased thrust chamber length. (L* 90).
- Run No. 1641 Durability testing of Al-Fin type thrust chamber. Minor coating flaking. Chamber removed for re-coating.

TABLE 1 (CONT)

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

Date		(6/11/56)	(6/12/56)						(6/21/56)							
Run No. (2CX-)		1643	1644A	1644B	1645	1646A	1646B	1647	1649	1650	1651	1652	1653	1654	1655	1656
P_{ch}	(psia)	279	280	282	593	597	609	546	289	294	316	304	299	276	286	267
W_o	(lb/sec)	13.6	14.16	14.16	29.73	28.54	28.54	24.38	14.45	14.55	14.75	14.12	14.19	13.50	13.12	12.93
W_f	(lb/sec)	2.31	2.18	2.16	3.10	4.15	4.12	4.3	1.65	1.92	2.98	2.91	2.76	2.27	2.84	2.28
W_t	(lb/sec)	15.91	16.34	16.32	33.13	32.69	32.66	28.68	16.05	16.47	17.73	17.03	16.95	15.77	15.96	15.21
O/F		5.887	6.495	6.556	8.744	6.877	6.927	5.67	8.97	7.48	4.95	4.85	5.13	5.95	4.62	5.67
C*	(ft/sec)	4398	4298	4333	4502	4610	4707	4572	4577	4640	4257	4480	4500	4400	4500	4405
F	(lb)	2990	3000	3130	6980	6930	7070	5990	3200	3100	3460	3270	3400	3000	2990	2810
I_{sp}	(lb/lb-sec)	187.9	183.6	191.8	210.7	212.0	216.5	208.8	199	189	195	192	200	190	188	185
C_F		1.375	1.374	1.424	1.506	1.479	1.479	1.47	1.43	1 36	1.40	1.38	1.46	1.39	1.34	1.35
t	(secs)	6.25	5	5.52	5.'8	6	5.8	4.11	4.19	7.46	5	5	5	5	5	5
$\Delta P_{C\,B}$	(psi)	87	85	85	140	126	126	149	106	93	104	104	78	100	104	100
ΔP_f	(psi)	102	134	---	339	489	---	503	86	102	240	221	207	186	215	157
$\Delta P_{T\,C}$	(psi)	---	---	---	---	---	---	75	---	---	---	---	---	---	---	---
$\Delta t_{T\,C}$	(°F)	---	---	---	---	---	---	10	---	---	---	---	---	---	---	---
Thrust Chamber		300869 Ser. No. 410-3 Ceramic						301298-C Ser. No.9 Al-Fin - Rokide Z	300868 Ser. No. 410-3 Ceramic							
H_2O_2 Injector		301325 Ser. No. 523-1														
Fuel Injector		300922 Ser. No. 519-1 Poppet (0.048 Gap)									300922 Ser. No. 519-2 Poppet (0.050 Gap)					
Catalyst Bed Serial No.		401646 Ser. No. 11														
Sonic Choke		301719-10														
Sonic Choke Throat Area (in.^{2})		3.40 in.^{2}														
Sonic Choke Pressure Ratio		0.770	0.760	0.769	0.751	0.769	0.784	0.828	0.785	0.746	0.805	0.807	0.800	0.755	0.827	0.771

Remarks:
- Run Nos. 1643-1646: Performance evaluation of conical sheet poppet-type fuel injector.
- Run No. 1647: Durability testing of Al-Fin type thrust chamber. Coating flaking in nozzle. Chamber removed for re-coating.
- Run Nos. 1649-1656: Performance evaluation of conical sheet poppet type fuel injector.

TABLE 1 (CONT)

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

Date		(6/21/56)			(6/22/56)							(6/25/56)	(6/26/56)			
Run No. (2CX-)		1657	1658	1659	1660	1661	1662	1663	1664	1665	1666	1668	1669	1670	1671	1672
P_{ch}	(psia)	266	597	532	392	409	423	398	414	408	402	528	293	446	588	586
W_o	(lb/sec)	13.08	28.15	24.25	20.62	20.84	20.50	18.60	18.78	18.12	20.7	21.2	13.8	20.2	26.1	26.1
W_f	(lb/sec)	2.03	4.41	4.54	1.92	2.47	2.87	3.27	3.90	4.52	2.24	4.28	2.13	3.34	4.4	4.16
W_t	(lb/sec)	15.11	32.56	28.79	22.54	23.31	23.37	21.87	22.68	22.64	22.94	25.48	15.93	23.54	30.5	30.26
O/F		6.45	6.38	5.34	10.80	8.45	7.14	5.69	4.81	4.02	9.24	4.95	6.48	6.05	5.94	6.28
C*	(ft/sec)	4425	4601	4650	4340	4260	4507	4350	4570	4510	4390	4760	4620	4790	4880	4880
F	(lb)	2780	6970	6150	4400	4610	4710	4540	4560	4490	4500	5858	3182	4949	6969	6910
I_{sp}	(lb/lb-sec)	184	214	213	195	197	202	207.5	201	198	196	230	200	210	228	230
C_F		1.34	1.46	1.48	1.45	1.49	1.44	1.47	1.41	1.41	1.44	1.55	1.39	1.42	1.51	1.50
t	(secs)	5	4	4	3	3	3	3	4	3	3	3	3	3	3	3
$\Delta P_{C\ B}$	(psi)	101	143	139	147	136	140	132	130	128	144	165	132	160	176	176
ΔP_f	(psi)	110	567	621	110	134	134	308	402	573	151	496	124	310	586	493
$\Delta P_{T\ C}$	(psi)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
$\Delta t_{T\ C}$	(°F)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Thrust Chamber		300868 Ser. No. 410-3 Ceramic →			300868 Ser. No. 410-4 Ceramic →							XC301298 Ser. No. 9 Al-Fin	300868 Ser. No. 410-1 (carbon steel extensic) Ceramic Chamber →			
H_2O_2 Injector		301325 Ser. No. 523-1 →														
Fuel Injector		300922 Ser. No. 519-2 Poppet (0.050 Gap) →														
Catalyst Bed Serial No.		401646 Ser. No. 11 →														
Sonic Choke		301719-10 →														
Sonic Choke Throat Area (in.^{2})		3.40 in.^{2} →														
Sonic Choke Pressure Ratio		0.765	0.794	0.817	0.705	0.732	0.768	0.803	0.826	0.836	0.715	0.850	0.770	0.823	0.829	0.829

Remarks:
- Run Nos. 1657-1666: Performance evaluation of conical sheet poppet type fuel injector.
- Run No. 1668: Durability testing of Al-Fin type thrust chamber. Nozzle erosion in region of coolant inlet manifold (Ref. 2CX1647).
- Run Nos. 1669-1672: Performance evaluation of conical sheet poppet-type fuel injector with increased thrust chamber length (L* 70).

TABLE 1 (CONT)

PRESSURIZED ENGINE TEST RESULTS

DATA SUMMARY

Date		(6/26/56)	(6/27/56)	(6/28/56)		
Run No. (2CX-)		1676	1677	1678	1679	1680
P_{ch}	(psia)	538	553	544	578	561
W_o	(lb/sec)	22.2	24.2	23.9	25.1	23.7
W_f	(lb/sec)	3.8	3.86	3.93	3.89	3.86
W_t	(lb/sec)	26.0	28.06	27.83	28.99	27.56
O/F		5.84	7.27	6.08	6.45	6.15
C*	(ft/sec)	4860	4620	4590	4680	4780
F	(lb)	5858	6050	6060	6232	6060
I_{sp}	(lb/lb-sec)	226	216	218	214	210
C_F		1.49	1.50	1.53	1.48	1.48
t	(secs)	4	20	60	70	7
$\Delta P_{C\ B}$	(psi)	142	168	158	173	192
ΔP_f	(psi)	N.R.	431	452	436	430
$\Delta P_{T\ C}$	(psi)	1	88	90	87	90
$\Delta t_{T\ C}$	(^oF)	12	32	32	31	24
Thrust Chamber		301960-10 Ser. No. 12 Al-Fin				
H_2O_2 Injector		301325 Ser. No. 523-1				
Fuel Injector		300922 Ser. No. 519-2 Poppet (0.050 Gap)				
Catalyst Bed Serial No.		401646 Ser. No. 11				
Sonic Choke		301719-10				
Sonic Choke Throat Area (in. ^{2})		3.40 in. ^{2}				
Sonic Choke Pressure Ratio		0.846	0.830	0.838	0.853	0.841

Remarks: Run Nos. 1676-1680: Durability testing of Al-Fin type thrust chamber. Nozzle erosion in region of coolant inlet manifold.

4. To check the functioning of turbopump "bootstrapping" as a starting method, and turbopump operation as a bi-propellant system operating in conjunction with the thrust chamber.

These objectives were accomplished at speeds ranging from 6,400 RPM to 14,900 RPM with little difficulty. In the absence of a throttle valve, all tests were conducted with fixed orifices in the oxidizer pump discharge outlet to adjust operating speed level.

To simulate chamber back pressure during turbopump testing without the thrust chamber and fuel injection system, an orifice plate was installed in the gas generator outlet. Subsequent difficulties with overspeed on starting necessitated the replacement of the orifice plate with the "sonic choke". Tests to date indicate that the "sonic choke" limits turbine overspeed during starting to less than 20,000 RPM without adverse effect on elapsed time from switch on to operating speed.

The speed limiting effect of the "sonic choke" is not dependent upon the "choke" throat area alone, but is determined by the relationship of the "choke" area to several factors including turbine nozzle area, turbine bypass area, pressure drops in the system between the oxidizer pump discharge and the inlet to the turbine nozzles, and the operating characteristics of both propellant pumps and the turbine. However, in general, increasing the "choke" throat area increases the speed to which the turbine will be limited; decreasing the "choke" area will reduce the maximum speed which the turbine can reach under "overspeed" conditions. The "choke" which was used during the above tests had a smaller throat area than the one which has been calculated for operation of the turboengine over a chamber pressure range from 245 psia to 560 psia for a thrust range of 3500 lbs. to 8000 lbs. (at the design altitude of 50,000 feet). Thus, when the larger "choke" area is used, a higher turbine speed (greater than 20,000 RPM) is anticipated under "overspeed" conditions.

After successfully testing the turbopump on a monopropellant basis (i.e. without a thrust chamber and fuel injection system), the No. 2 turbopump was readied for the first turboengine tests. The first of these was satisfactorily completed. After approximately 15 seconds of bi-propellant operation, excessive steam leakage was noted in the area of the turbine steam seal case, and the run was immediately terminated. Coincident with the operator's shutdown, a small fire was noted at the steam seal case vent. Inspection of the turbopump at disassembly revealed that the steam seal burned, causing considerable damage to the steam seal case and the shaft. Figure 8A illustrates the condition of the steam seal case, the turbine wheel, and the nozzle block. Damage sustained by the steam seal case and the heat shields which separate

REACTION MOTORS, INC. FIGURE 8 a PHOTO NO. 103-596
CONFIDENTIAL TITLE REPORT RMI 103-P3

SERIAL NO. 2 TURBOPUMP COMPONENTS AFTER SEAL FAILURE (Gas Generator Side)

REACTION MOTORS, INC. FIGURE 8 b PHOTO NO. 103-599
CONFIDENTIAL TITLE REPORT RMI 103-P3

SERIAL NO. 2 TURBOPUMP COMPONENTS AFTER SEAL FAILURE (Pump Side)

the fuel pump housing from the steam seal case, is illustrated in Figure 8B. The fuel pump case shown on the left of the illustration is undamaged due to the protection afforded by the heat shields.

It was clearly indicated that the fire took place in the region of the steam seal. The carbon ring seals broke and the increased friction of these carbon pieces against the rotating shaft caused the fire. Replacement of the carbon ring seals with a labyrinth type seal is now under consideration and tests have been initiated to determine the feasibility of this change.

One test was completed with a Cartriseal ceramic type steam seal. This test resulted in seizure of the seal and minor scoring of the shaft. After inspection of the assembly, it was concluded that certain critical clearances were too "tight" and expansion from heat during running had cause the seizure. One seal is being modified by the vendor in an attempt to obtain satisfactory clearance conditions.

An operating time of 3½ minutes was accrued on turbopump Serial No. 1, including monopropellant operation, and a teardown inspection indicated that all components were in excellent condition with the exception of the roller bearing where the internal clearance of this bearing was found to be inadequate. Provisions for sufficient clearance were made for turbopump Serial No. 2 and a total of 3¼ minutes of satisfactory operation, including monopropellant operation, was accrued before the start of the run during which the steam seal failure occured.

Publication of the data obtained during the above-mentioned tests will be furnished when detailed data reduction and data anlysis is accomplished.

3.2.2 Integrated Turbopump, Gas Generator, and Thrust Chamber Testing

The first attempt to operate the turbopump, gas generator and Al-Fin thrust chamber as an integrated bi-propellant turborocket engine proved completely successful. A second and longer duration test followed and with the exception of the turbine steam seal failure described in the preceding section (3.2.1) this test was equally successful.

Using test stand type valving and propellant manifolding, and fixed orifices in both pump discharge manifolds to adjust mixture ratio and level of operation, the test plan was to make a monopropellant "bootstrap" start and when stable operation was achieved, initiate fuel (JP-5) injection and operate on a bi-propellant basis for ten seconds. The test was performed successfully according to this plan at near the minimum thrust level.

Inspection of the major assemblies (without disassembling them) indicated no evidence of failure or incipient failures and a longer duration run was initiated. It was planned to operate the engine for 60 seconds during this run, however, the run was terminated after approximately 15 seconds of bi-propellant operation because of excessive steam leakage which was observed in the area of the turbine steam seal case. This and the steam seal failure which was discovered upon subsequent examination are discussed in section 3.2.1. With the exception of the steam seal failure and the consequent damage, all other subassemblies of the basic turboengine appeared in excellent condition.

It was significant that the first attempt to operate the integrated basic turboengine was completely successful. The first two runs demonstrated rapid "bootstrap" starts, and stable monopropellant and bi-propellant operation with the "Topping Turbine" type turborocket engine system.

3.2.3 Catalyst Bed and Gas Generator

Catalyst bed life testing was continued on the Serial No. 7 catalyst bed on Becco Hydrogren Peroxide during this report period. Test operations were conducted using an orifice plate to simulate back pressure at the bed outlet. Time was accrued by making alternate high flow and low flow runs. The flows tested were approximately 18 and 32 lbs/min/in^2 and approximately 2 minutes duration was accrued on each test. A total of two hours of satisfactory operation was completed during this report period, extending the total bed operating life to over three hours. Catalyst efficiency as measured by decomposition temperature was unchanged. Pressure drop through the bed increased from 65 to 165 PSI; maximum design pressure drop is 180 PSI. Figure 10 is a plot of the pressure drop versus throughput (flow rate divided by bed cross sectional area) characteristics of this bed during the course of operation, and is a continuation of figure 10 in Report RMI-103-P2.

3.2.4 Al-Fin Thrust Chamber Durability

Five flanged Al-Fin type 8000 pound thrust chambers of the type illustrated in figure 9 were subjected to test evaluation during this report period. The first thrust chamber tested, Serial No. 5, had been reworked at the flange end in an effort to eliminate the failures associated with the steel seal ring insert, which was discussed in Section I.a. of Report RMI-103-L3. The steel ring was incorporated to reduce potential long term corrosion effects on the flange seal face. The rework entailed the removal of the aluminum adjacent to the seal ring at the flange end of the thrust chamber. Rokide Z (Zirconia) refractory coating was then applied over the newly exposed surfaces. Three short duration monopropellant tests at progressively increased tank pressure were

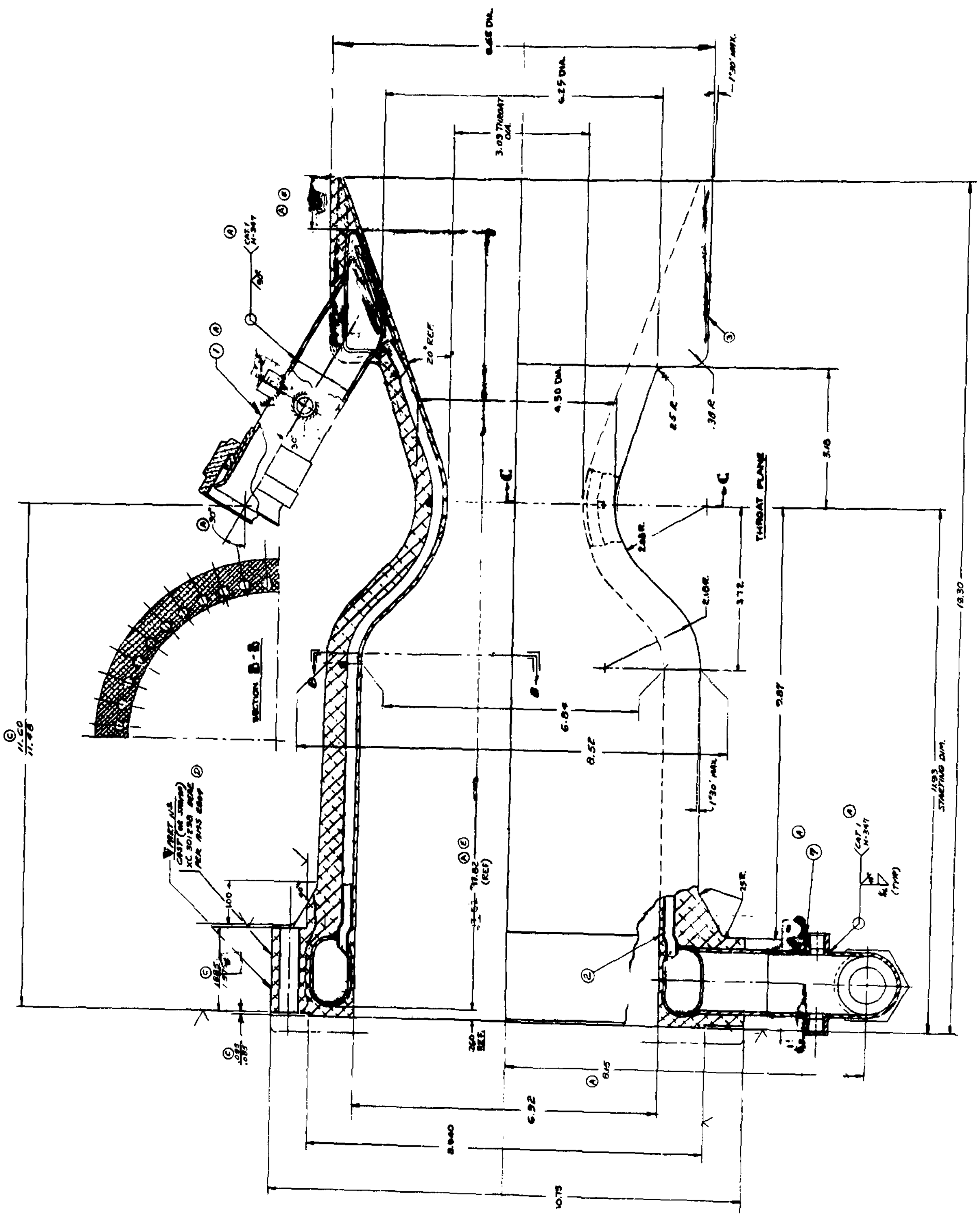

FIGURE 9

TITLE 8000-LB-THRUST AL-FIN CHAMBER

PHOTO NO. 103-637

REPORT RMI 103-P3

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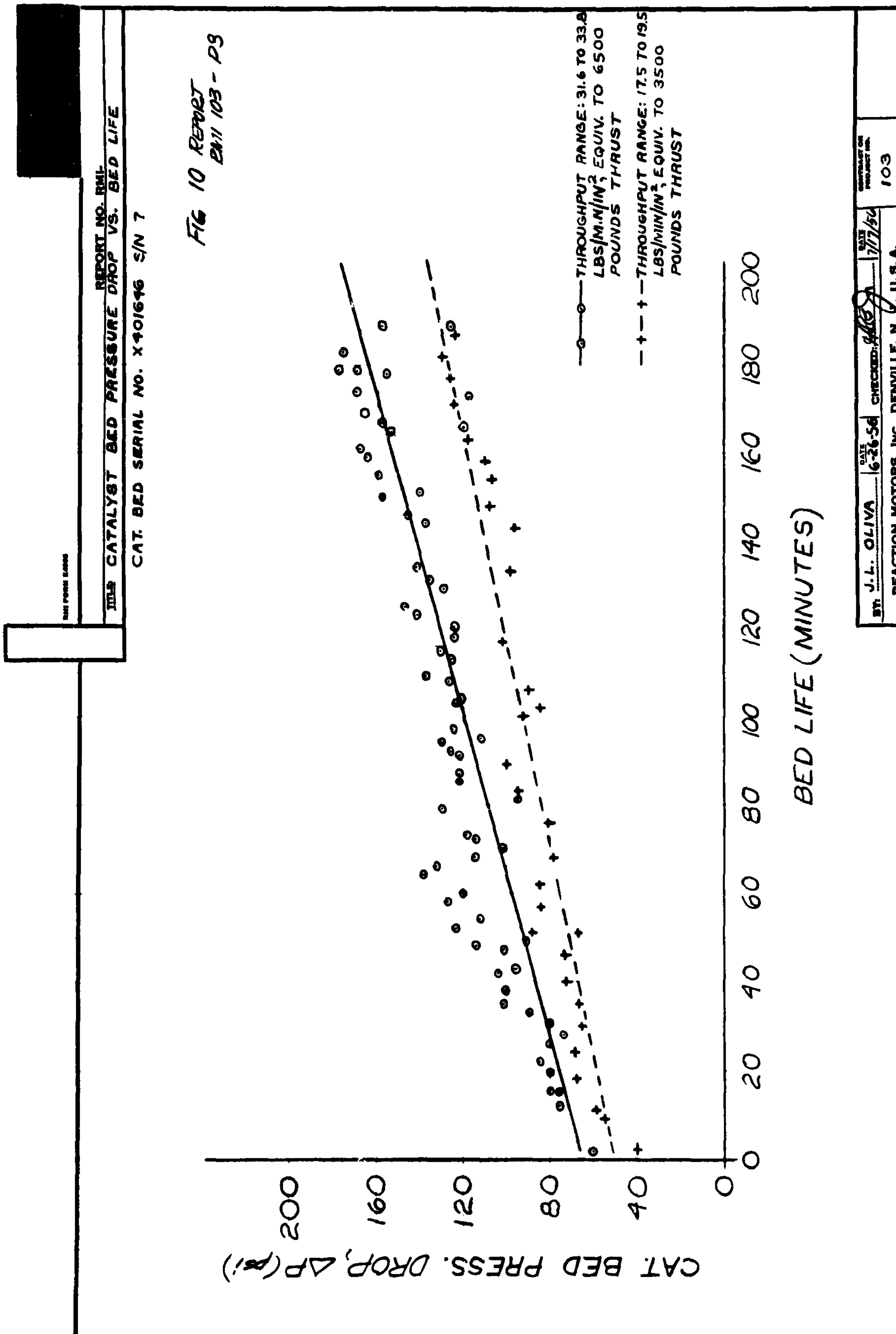
REPORT NO. RMI-
TITLE CATALYST BED PRESSURE DROP VS. BED LIFE
CAT. BED SERIAL NO. X401646 S/N 7
FIG 10 REPORT RMI 103 - P3
THROUGHPUT RANGE: 31.6 TO 33.8 LBS/MIN/IN², EQUIV. TO 6500 POUNDS THRUST
THROUGHPUT RANGE: 17.5 TO 19.5 LBS/MIN/IN², EQUIV. TO 3500 POUNDS THRUST
CAT. BED PRESS. DROP, ΔP (psi)
BED LIFE (MINUTES)
0
20
40
60
80
100
120
140
160
180
200
BY: J.L. OLIVA
DATE 6-26-56
CHECKED:
DATE 7/7/56
103
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conducted. After the third test, inspection of the thrust chamber revealed that the aluminum and the steel seal insert had burned and damaged the chamber beyond further use. The aluminum had again reached its kindling temperature, locally, due to poor cooling conditions resulting in a fire of sufficient intensity to burn the steel insert. It was then decided to abandon further manufacture or test of thrust chambers containing the steel insert ring. If long term corrosion of the aluminum flange seal face proves to be a significant problem, corrective action will then be taken.

The next four Al-Fin chambers subjected to durability testing were Serial No's 7, 8, 9 and 12. None of these chambers contained a steel insert ring. Each of these chambers failed in the exit cone region during the initial or first few bi-propellant tests. The failures involved loss of the Rokide Z coating and a resultant erosion of the aluminum underneath. The causes fell into three categories:

1) "Cold shuts" in the casting which did not provide a sound "footing" for the coating.

2) Deflection or "bulging" of the annular coolant manifold imbedded in the cast aluminum near the exit end, and absence of a sound bond between the aluminum and the manifold.

3) Lack of adequate cooling for the aluminum which extends past nozzle exit manifold.

It is significant that the throat and entrance cone regions in particular, as well as the chamber region have exhibited a consistent freedom from failures of the Rokide Z coating. The throat and entrance cone region is usually the most critical area in thrust chamber development since the highest local wall temperatures are encountered in this region.

The failures in the exit cone region appear to be capable of straightforward solutions. The "cold shuts" are currently being eliminated as a result of casting technique modifications. The deflection of the coolant collector manifold under pressure is being minimized by reinforcing the manifold structure. This deflection and the resultant failure is clearly shown in Figure 11. The circumferential cracking of the aluminum and refractory coating followed by stripping and erosion can be readily seen. Casting techniques are being improved to obtain sound bonds in the manifold region to eliminate the cause of these failures. Improved cooling for the aluminum extending beyond the collector manifold will be provided by extending the manifold toward the exit. Immediate, but temporary action has been taken to eliminate failures in the manifold region at the exit end for those chambers which have already been cast or are in the process of being cast. The

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FIGURE 11 PHOTO NO. 103-520

TITLE REPORT RMI 103-P3

VIEW SHOWING SERIAL NO. 9 AL-FIN THRUST CHAMBER
FAILURE IN EXIT REGION (Note Circumferential Cracking)

aluminum is stripped from the stainless steel manifold on the inside surface and at the exit end. Rokide Z (Zirconia) is then applied directly to the stainless steel manifold.

3.2.5 Fuel Injector Evaluation

Performance (C*) evaluation of the basic 120° included angle conical sheet type fuel injector (Part No. X300922, shown in Fig. 12) was conducted at both high and low chamber pressures with a ceramic thrust chamber without a "sonic choke". The results of these tests are shown in Figure 13. From these tests a performance comparison with previously evaluated fuel injectors was obtained. A summary is provided in Table II. This comparison indicates that the conical sheet type injector yields a C* about 8½% lower than the other types. In addition, a cylindrical extension was added to the ceramic thrust chamber increasing thrust chamber L* from 50 to 95 inches. Further evaluation of the conical sheet injector was then conducted at high chamber pressure. The chamber extension test setup is shown in Fig. 14 and performance results are given in Fig. 15. At a mixture ratio (O/F) of 7.0 and a chamber pressure of 625 psia, C* was increased from 4330 ft/sec. to 4685 ft/sec. approximately an 8% increase.

3.2.6 Sonic Choke Ignition and Performance Testing

A "sonic choke" was assembled with a gas generator and thrust chamber and run with pressurized propellants to evaluate fuel ignition characteristics and to ascertain the influence of the choke on thrust chamber performance (C*). For these tests the conical sheet, poppet type fuel injector (Part No. X300922) was used. Additional tests were performed with a short chamber extension which increased L* approximately 50% to L* = 78 inches. Fuel ignition proved consistently satisfactory in all "sonic choke" tests and the performance results are summarized in Figure 15. Comparing the results at an O/F ratio of 7.0 low chamber pressure, and an L* value of 50 inches with the results in Figure 13 under similar operating conditions, it can be deduced that the "sonic choke" increases C* by 220 ft/sec. or more than 5%. The effect of the 50% increase in L* on the performance with the "sonic choke" indicates that an O/F ratio of 6.5 and at high chamber pressure, an increase in C* of 300 ft/sec. or approximately 6% is achieved (See Figure 15).

3.3 OXIDIZER SUPPLY SYSTEM DEVELOPMENT

Progress in the development of the oxidizer supply system was limited to the continuation of the component procurement survey and preliminary design work on revision of the system for the F8U-1 dorsal fin installation. The

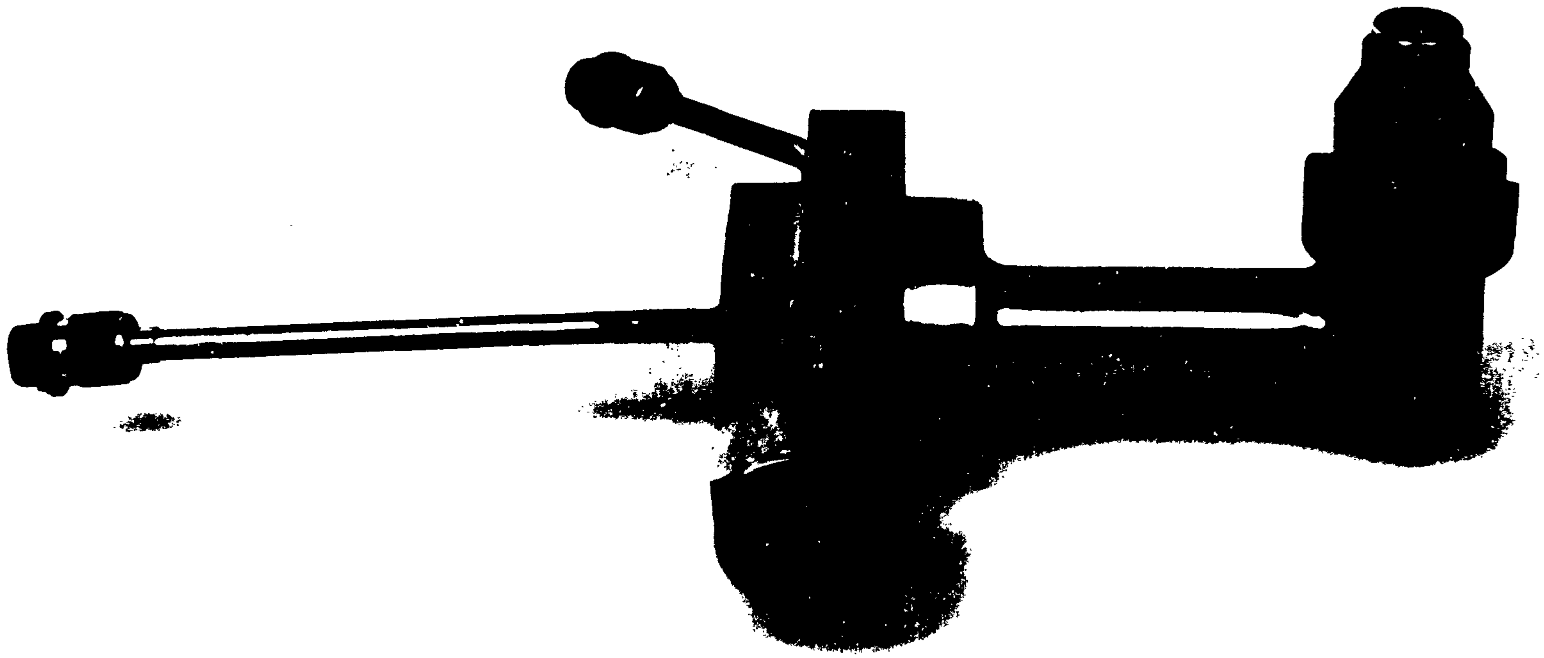

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FIGURE 12 PHOTO NO. 103-610
TITLE REPORT RMI 103-P3

120° CONICAL SHEET TYPE FUEL INJECTOR
(X300922) AND MOUNTING POST

FIG. 13 REPORT RMI 103-P3

CHARACTERISTIC VELOCITY VS. MIXTURE RATIO

(NON SONIC CHOKE OPERATION)

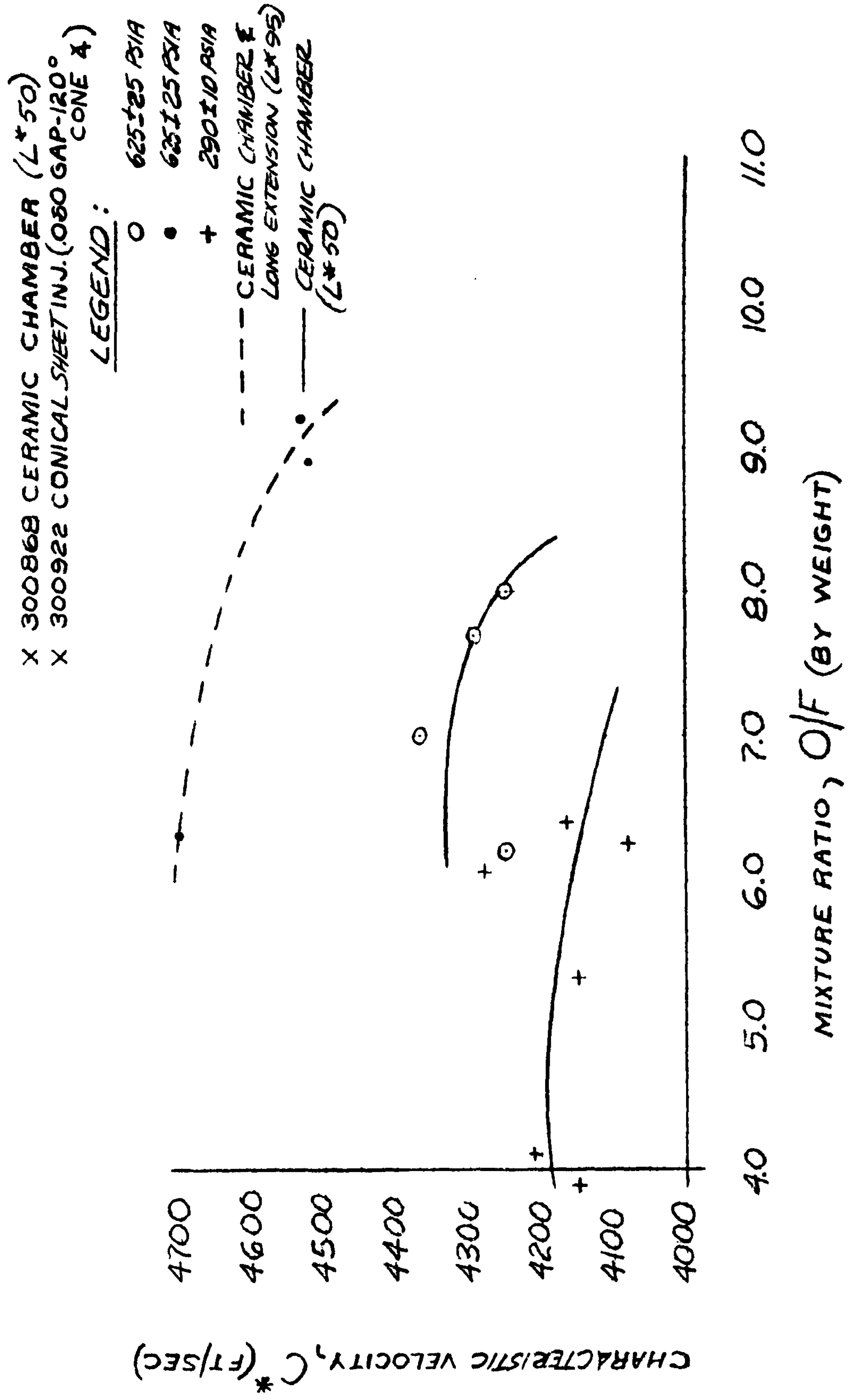

TABLE II

FUEL INJECTOR PERFORMANCE COMPARISON (1)

	Chamber L* Inches	O/F	Pch (psia)	C* ft/sec	Run No. 2CX-
Rated Conditions		7.0	665 (2)	4970	
Conical Sheet Poppet Injector (thick sheet) X300922	50	6.9	640	4370	1630C
Conical Sheet Poppet Injector (thin sheet) X300899	50	6.7	662	4300	1394
Finger Injector X300731	50	6.8	665	4700	1415
Radial Stream Poppet Injector X300918	50	7.0	510	4770	1403
Radial Stream Poppet Injector X300923	50	5.6	504	4610	1409

NOTES:
(1) Tests were made without "Sonic Choke"
(2) Rated chamber pressure has now been reduced to 560 psia for the 8000 lb. thrust level.
(3) The X300922 conical sheet injector has a sheet thickness approximately twice that of the X300899 injector.
(4) The X300918 injector has 12 small and 4 large radial injection holes. The X300923 injector has 16 equal size radial injection holes.

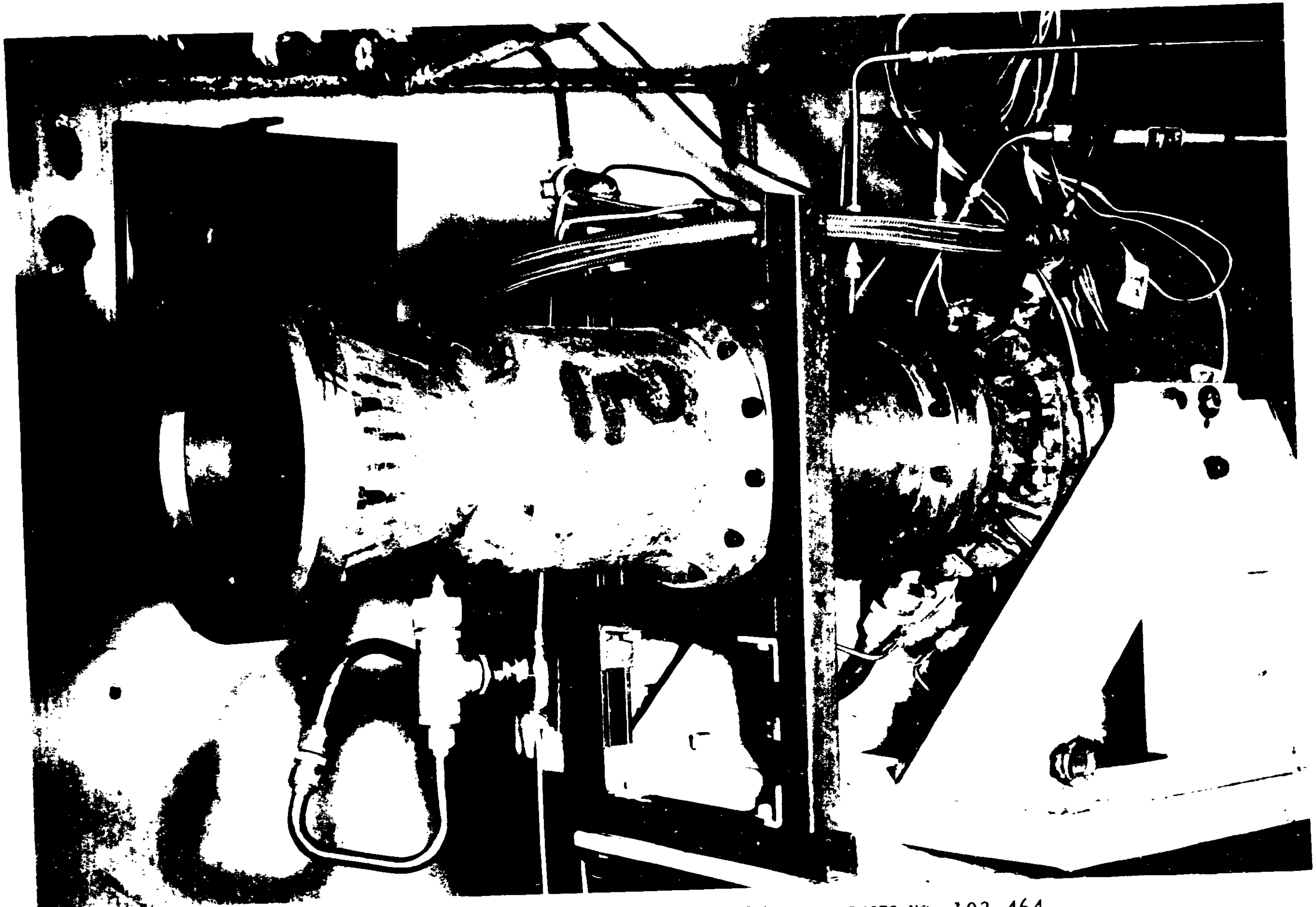

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FIGURE 14
TITLE

PHOTO NO. 103-464
REPORT RMI 103-P3

CERAMIC THURST CHAMBER AND L^* EXTENSION
INSTALLED ON PRESSURIZED ENGINE

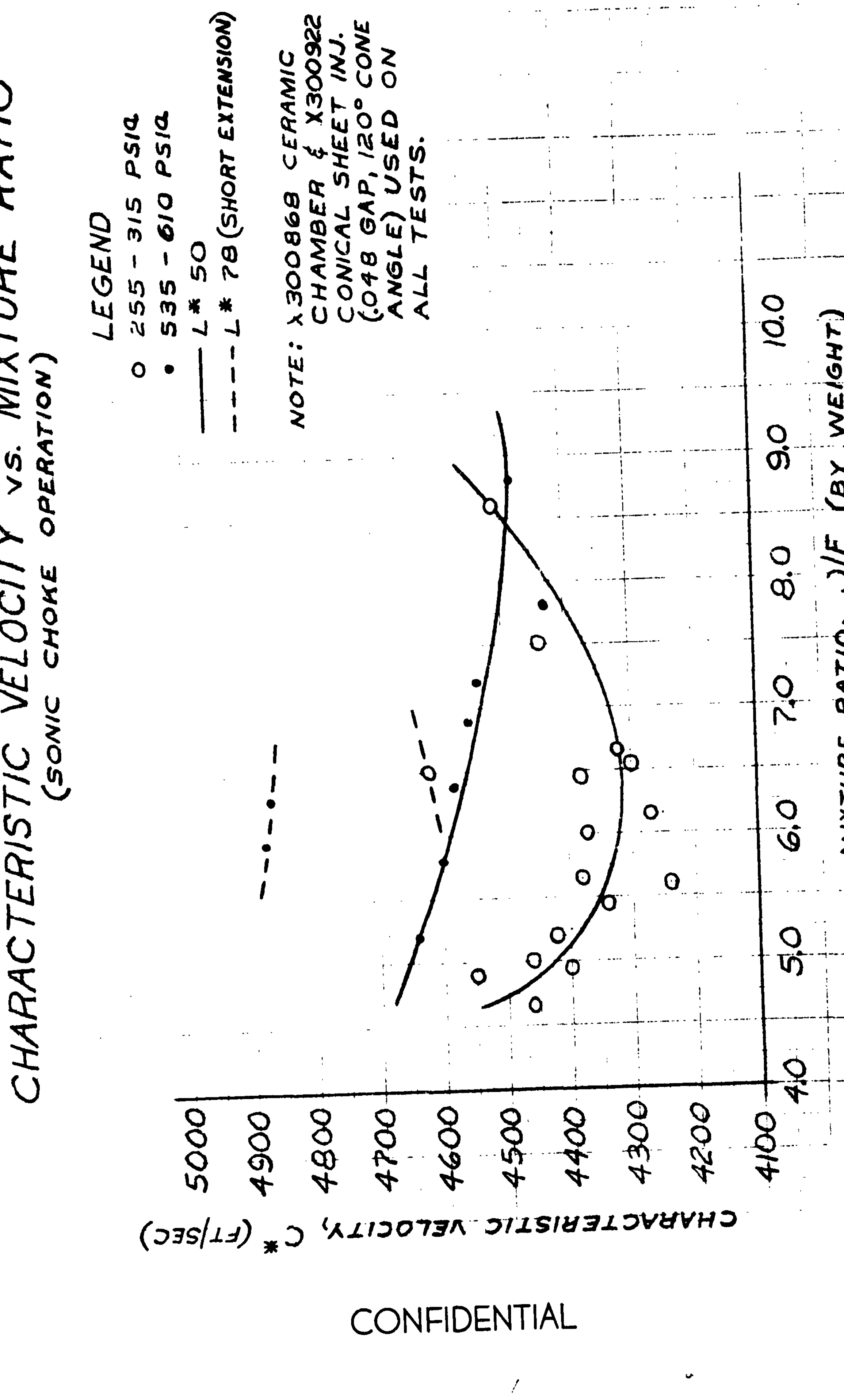

FIGURE 15
REPORT RMI 103-P3

major effort in the development of this system, with the exception of the boost pump, can not be accomplished until Chance Vought receives authorization for work on the thrust augmented aircraft.

3.4 AIRFRAME INSTALLATION LIAISON

Liaison between RMI and Chance Vought Aircraft has been continued through telephone conversations and the meeting noted in section 2.5. Liaison activity will be accelerated following receipt of the thrust augmented aircraft contract by Chance Vought.

3.5 HYDROGEN PEROXIDE CONTAMINANT STUDY

Testing on the contaminant program during this report period has been directed at confirming acceptable operation with the following concentrations of contaminants:

Contaminant Ion	Concentration of Ion Tested
Phosphate	0.5 mg/1
Tin	4.0
Sulfate	2.5
Nitrate	5.0
Aluminum	0.5
Chloride	0.75
Ammonium	1.0

Various tank car samples of Becco and duPont commercial 90% hydrogen peroxide were analyzed and adjusted to the above concentrations. One adjusted sample of Becco H_2O_2 and one of duPont H_2O_2 were tested in the small scale catalyst bed with the following results.

Run #	Peroxide	Results
3043	Becco	A total run time of 75 minutes, all within the acceptable operating condition.
3048	duPont	Incomplete decomposition was observed after 67 minutes of operation.

The adjusted sample of Becco peroxide gave good performance. However, the catalyst bed used with the adjusted sample of duPont H_2O_2 failed to completely decompose the hydrogen peroxide after 67 minutes of operation. This latter test will be repeated during the next report period to determine whether the catalyst bed or the adjusted peroxide was responsible.

Due to questions raised concerning the possible effects produced by different phosphate ions, hydrogen perioxide was contaminated with the pyro and ortho phosphate ions. Results of small scale bed testing show no significant difference due to either form of the phosphate contaminant.

Analytical techniques for simple, rep. ducible methods of detecting the above contaminants at the levels proposed are under study. Improvements in analytical techniques and methods, particularly for the sulfate and nitrate ions have been proposed and are being discussed with analytical personnel from Becco, NARTS and NRL.

Several small scale catalyst bed life tests have been performed with screen beds prepared specifically to resemble the conditions and materials used in the catalyst bed of the XLR40-RM-2 engine. Three tests were performed with commercial tank car lots of Becco H_2C_2 and three with duPont H_2O_2.

Run #	Peroxide	Results
3027	Becco	An excessive catalyst bed pressure drop after 100 minutes of operation.
3028	Becco	An excessive catalyst bed pressure drop after 80 minutes of operation.
3049	Becco	A total run time of 176 minutes, all within the acceptable operating conditions.
3030-31-42	duPont	Incomplete decomposition observed after 148 minutes of operation.
3045	duPont	Incomplete decomposition observed after 162 minutes of operation.
3047	duPont	A total run time of 199 minutes within acceptable operating conditions.

Of these life tests all of Becco and only one of duPont were acceptable. The two failures with duPont H_2O_2 were due to incomplete decomposition. However, two of the Becco tests were considered poor due to a high catalyst bed pressure drop. This phenomenon is now being studied.

Several special catalyst bed configurations have been prepared to study possible improvement in catalyst life and reduction of bed pressure drop. Two configurations were tested.

Run #	Description of Bed	Results
3049	An extra 6 stainless steel screens are included at the beginning of the bed.	An excessive catalyst bed pressure drop after 56 minutes of operation.
3052	Reduction of 5 catalyst and 5 stainless steel screens.	Total run time 467 minutes all within acceptable operating conditions.

The only result with any significance was a bed with a reduced catalytic screen. Run No. 3052 is significant; this bed operated under normal conditions for a period of eight hours with no indication of failure.

Several other beds with different silver screen distribution patterns were prepared as part of the overall catalyst development program. Testing of these configurations will be undertaken during the next report period.

Compilation of the data and results of L.P.E. runs and small scale catalyst bed operation on contaminated H_2O_2 has continued.

4. FUTURE WORK

4.1 Design

1. Adapt the functional design features of the face shut-off fuel injector valve to the new formal engine configuration.

2. Prepare a formal turboengine assembly drawing based on evaluation design parts.

3. Start a formal engine assembly drawing, including valve and control components and all piping and wiring.

4. Design a fuel cooling and lubricating system for the turbopump roller bearing.

5. Start an engine weight study to reduce the weight of evaluation engine parts to be used in the formal engine design.

6. If Chance Vought has received contractual authorization for the thrust augmented F8U-1 aircraft, present RMI recommendations on propellant supply system design and component function as well as latest engine installation requirements.

4.3 Manufacturing and Procurement

1. Continue fabrication of Al-Fin thrust chambers as required for test.

2. Initiate procurement of two more concentric shell thrust chamber helical liners.

3. Complete the fabrication of the first swaged tube spaghetti 45 tube chamber.

4. Fabricate workhorse concentric shell thrust chamber, using the helical liner.

5. Complete fabrication and assembly of gas generator, Serial Nos. 6, 7, and 8; and start fabrication of Serial Nos. 9 through 12.

6. Complete assembly of Serial No. 3 turbopump. Start subassembly of Serial Nos. 4, 5 and 6 turbopumps.

7. Assemble basic turboengine Serial No. 2, using turbopump No. 2, and an experimental throttle valve for durability testing.

8. Expedite procurement of vendor control components, tubing, fittings, electrical components and wiring.

9. Construct a metal parts mockup of the controls integrated engine to establish initial placement of control components and tubing and wiring configurations and lengths.

10. Assemble a fully controlled engine including valves, pressure switches, control box, piping and wiring.

11. Continue fabrication of detailed parts for boost pump Serial Nos. 1 and 2.

4.3 Testing

1. Continue pressurized life testing of Rokide Z coated 8000 pound Al-Fin thrust chambers.

2. Perform catalyst bed life test on duPont hydrogen peroxide.

3. Initiate testing of vortex generator for C* improvement, and thrust chamber wall atmosphere control.

4. Initiate testing of a workhorse concentric shell thrust chamber.

5. Continue turborocket engine tests with an integrated thrust chamber, gas generator and turbopump, to evaluate engine endurance.

6. Perform throttling tests on an integrated turbopump engine using the non-integrated design H_2O_2 throttle valve.

7. Continue evaluation testing of engine control components.

8. Start tests on a fully controlled turborocket engine. Controls will include experimental throttle and shut-off valves, a face shut-off fuel injector, control box, and associated wiring and piping.

4.4 H_2O_2 Contaminant Study

1. Compile all data and results obtained during the contaminant study.

2. Prepare data for a preliminary hydrogen peroxide specificati[illegible] and review its contents with interested agencies such as Bec[illegible], duPont, NRL, and NARTS.

3. Continue studies on the effect of catalyst bed configuratio[illegible] [illegible]n catalyst life and bed pressure drop.